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INTERPRETATION OF SEISMIC MEASUREMENTS TAKEN IN THE DIAMOND MINE SERIES

Informal Technical Report

R. McLAUGHLIN
D. E. WILLIS

MAY 1972

GEOPHYSICS GROUP - INFRARED AND OPTICS DIVISION
Willow Run Laboratories
INSTITUTE OF SCIENCE AND TECHNOLOGY

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13. ABSTRACT

The Geophysics Section of the Infrared and Optics Division of the Willow Run Laboratories has participated in the MIGHTY MITE series of experiments at the Nevada Test Site by measuring and analyzing near-field seismic phenomena resulting from the events of the series. This technical report discusses in detail the results from the DIAMOND MINE and the DIAMOND MINE HE shots, and makes correlations between these events and the DIAMOND DUST event.

The trace amplitudes of broadband seismograms showed that DIAMOND MINE was on the average a factor of 1.6 (with a maximum of 2.5) larger than DIAMOND DUST. The spectral ratios of DIAMOND MINE to DIAMOND DUST showed that at 2 Hz, DIAMOND MINE was on the average a factor of 3.2 to 5.6 larger than DIAMOND DUST. The spectral ratios at this typical low frequency are believed to be a more accurate indicator of the effective decoupling than the spectral ratios at higher frequencies.

On the basis of coda length magnitude (M_D) determinations, DIAMOND MINE was 0.4 of a magnitude unit larger than DIAMOND DUST which would indicate a decoupling factor of 2.5 for DIAMOND DUST.

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On the basis of coda length magnitude (M_D) determinations, DIAMOND MINE was 0.4 of a magnitude unit larger than DIAMOND DUST which would indicate a decoupling factor of 2.5 for DIAMOND DUST.

INTERPRETATION OF SEISMIC MEASUREMENTS TAKEN IN THE DIAMOND MINE SERIES

1 INTRODUCTION

This report describes the additional field measurements and data analyses performed by the University of Michigan in connection with the continuation of the MIGHTY MITE series. Specifically included are the data obtained for DIAMOND MINE and the high explosive (1000 pounds of nitromethane) shot. The results of DIAMOND DUST were reported in a previous report (Willis and Hand, 1971). Also included in this report is a review of data obtained from the Nevada seismograph net. Analysis of this data has not been completed yet.

The University of Michigan's Geophysics Laboratory established five portable seismograph stations to record these two events. The same locations shown in figure 1-1 were used for the first shot (DIAMOND DUST) of the series. Three-component short-period seismographs were used at each site. Additional vertical high frequency seismometers and a broadband microphone were used at the Pahute Mesa site which was located 6+ km north-northeast of ground zero.

2 FIELD MEASUREMENT DATA AND RESULTS

2.1. UNIVERSITY OF MICHIGAN DATA

Good recordings were obtained for both shots at all five stations. Seismograms and spectral analyses for both events are contained in Appendices A through D. Composite spectral curves showing the vertical and longitudinal components of the first compressional wave arrival for all three shots are shown in figures 2-1 through 2-10 for each of the five stations. DIAMOND MINE produced higher signal levels below 12.5 Hz but DIAMOND DUST and the HE shot produced higher relative energies than

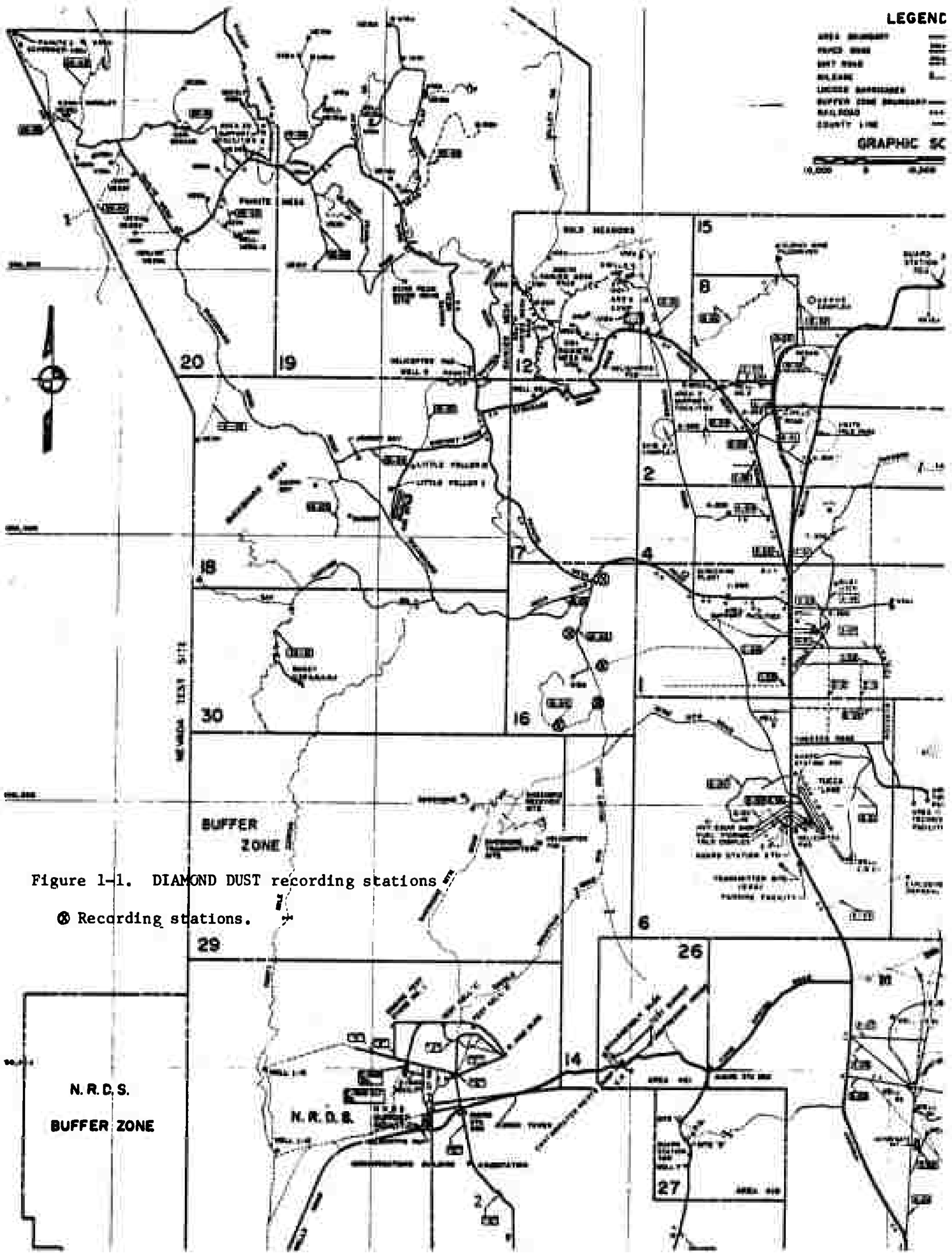

Figure 1-1. DIAMOND DUST recording stations

⊗ Recording stations.

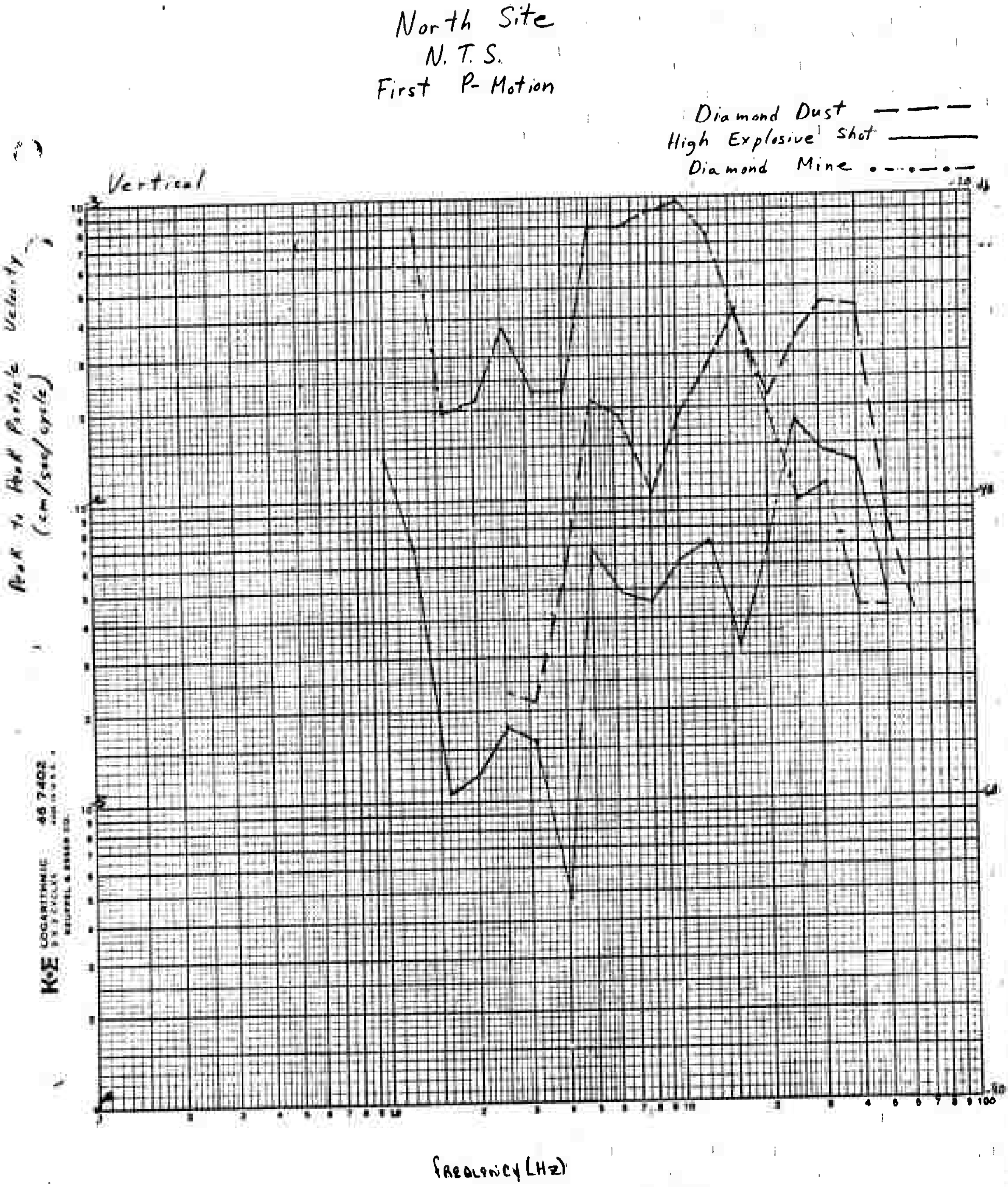

Figure 2-1. North Site, NTS, First P Motion

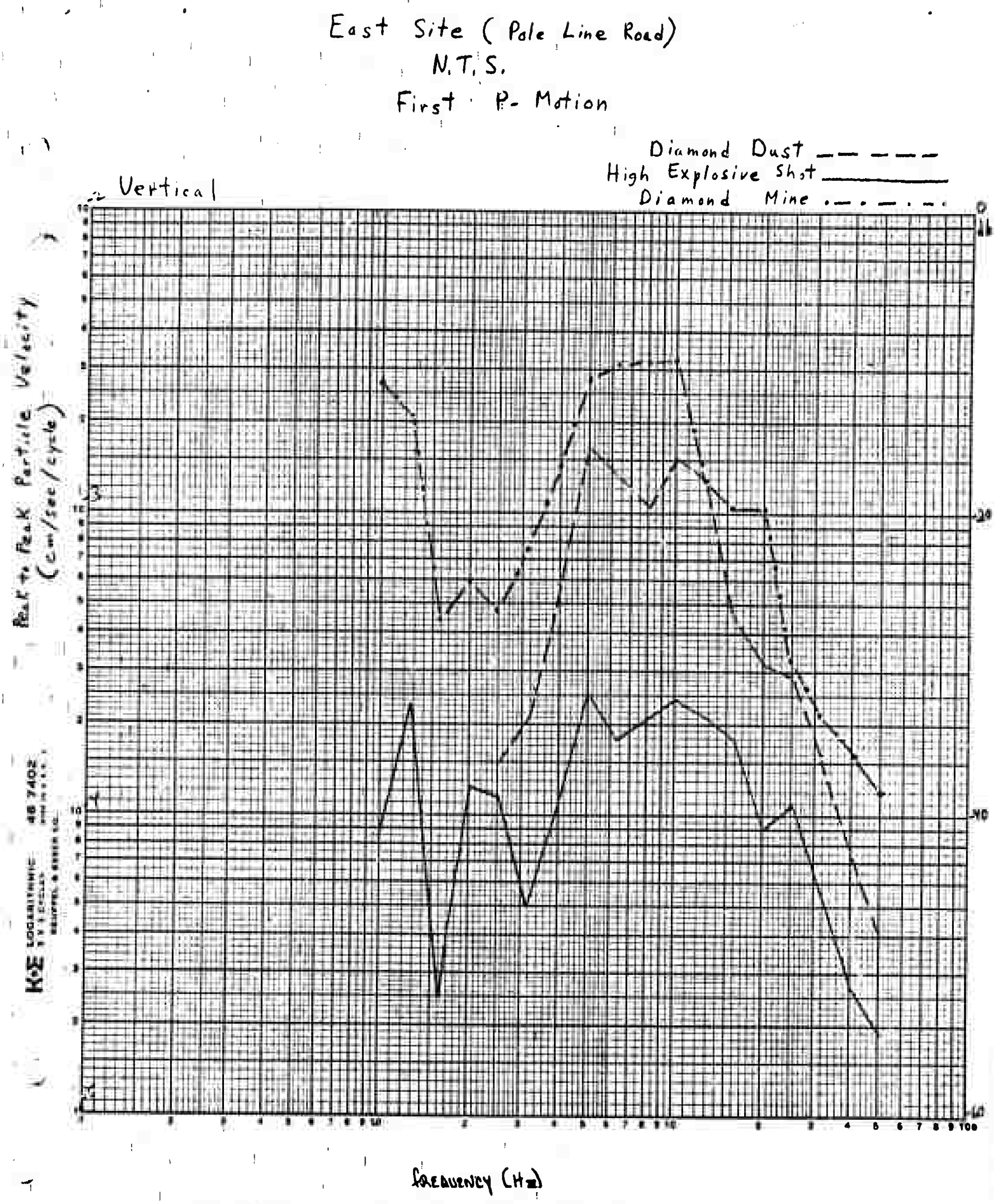

Figure 2-2. East Site (Pole Line Road), NTS, First P Motion

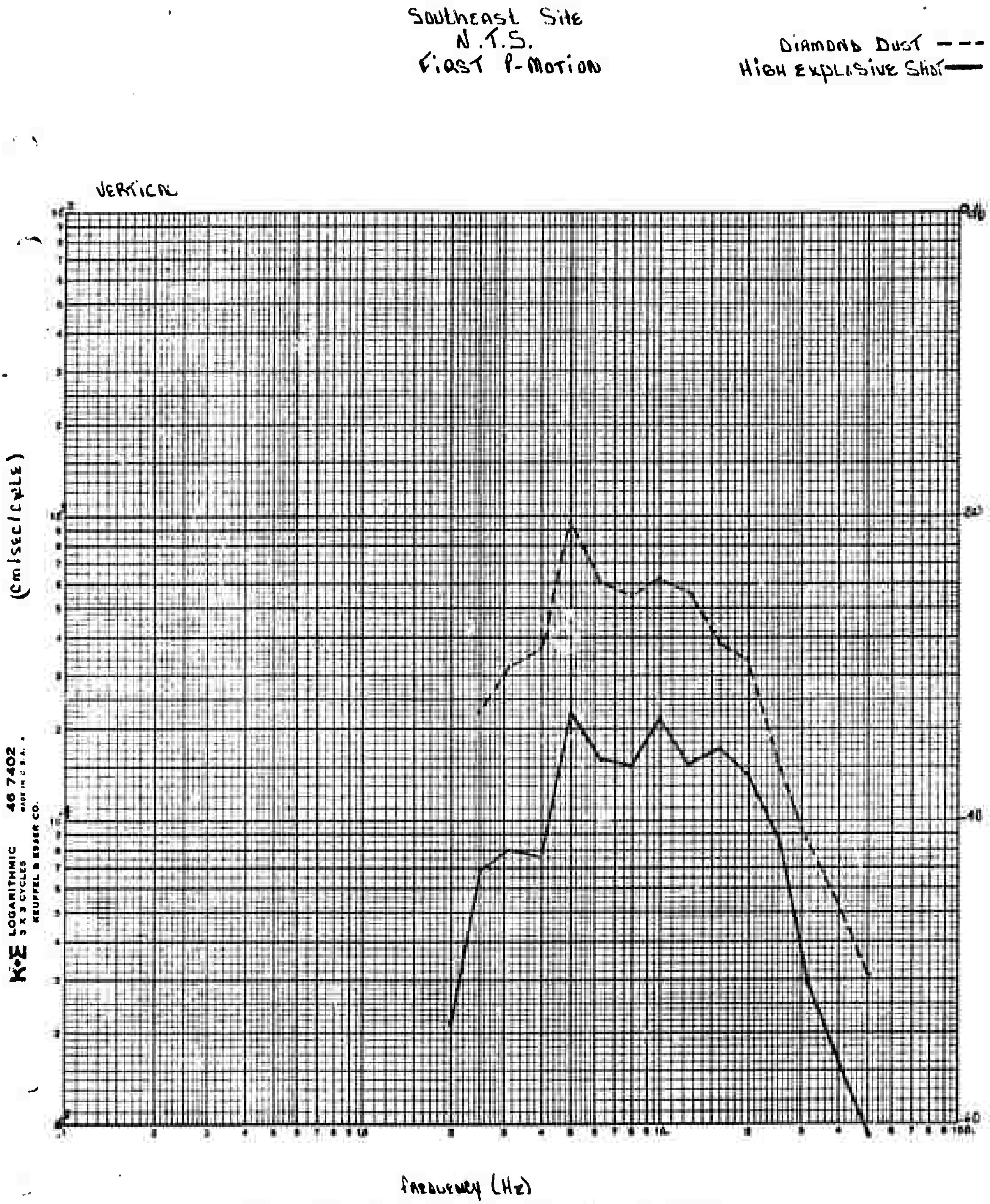

Figure 2-3. Southeast Site, NTS, First P Motion

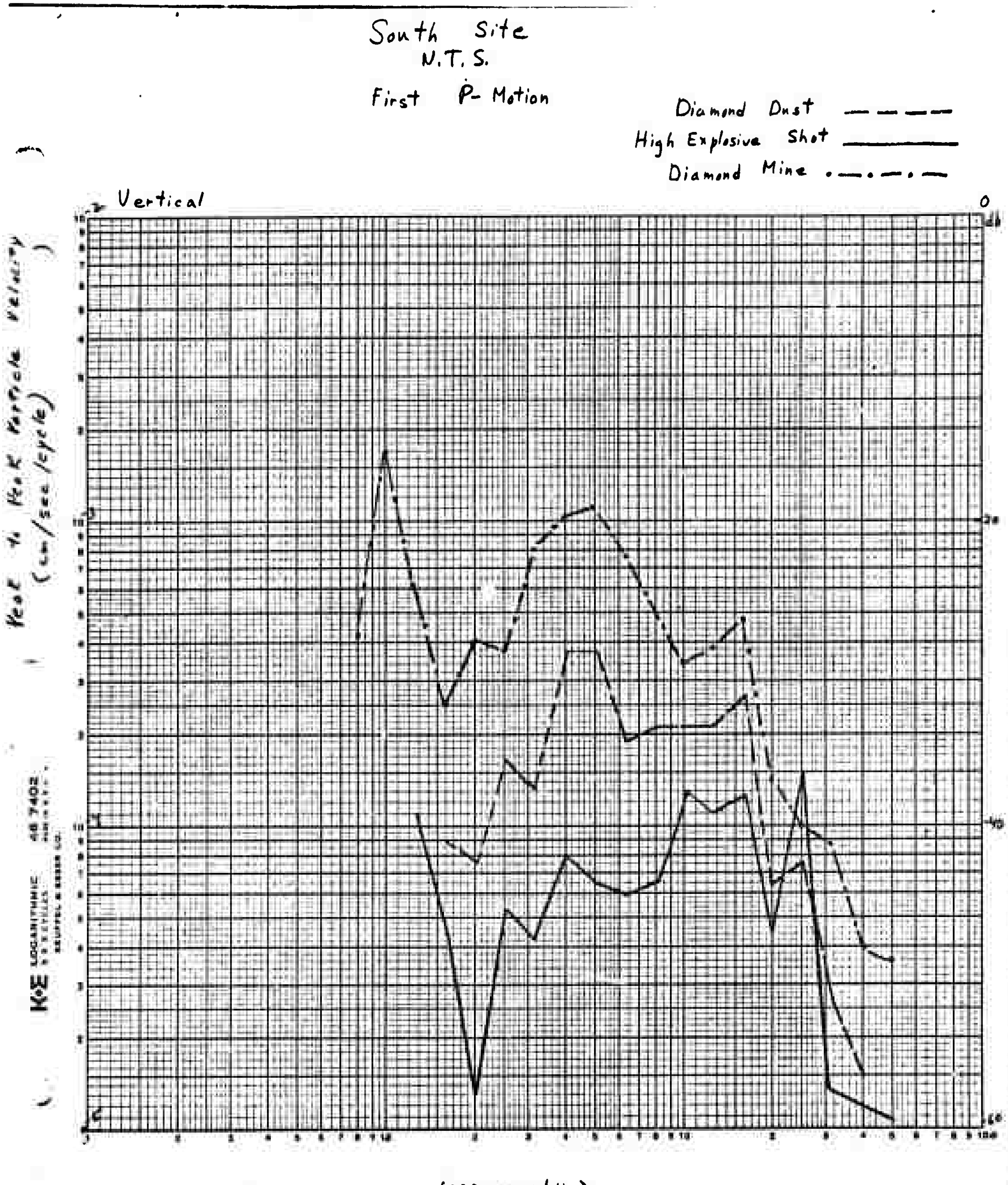

Figure 2-4. South Site, NTS, First P Motion

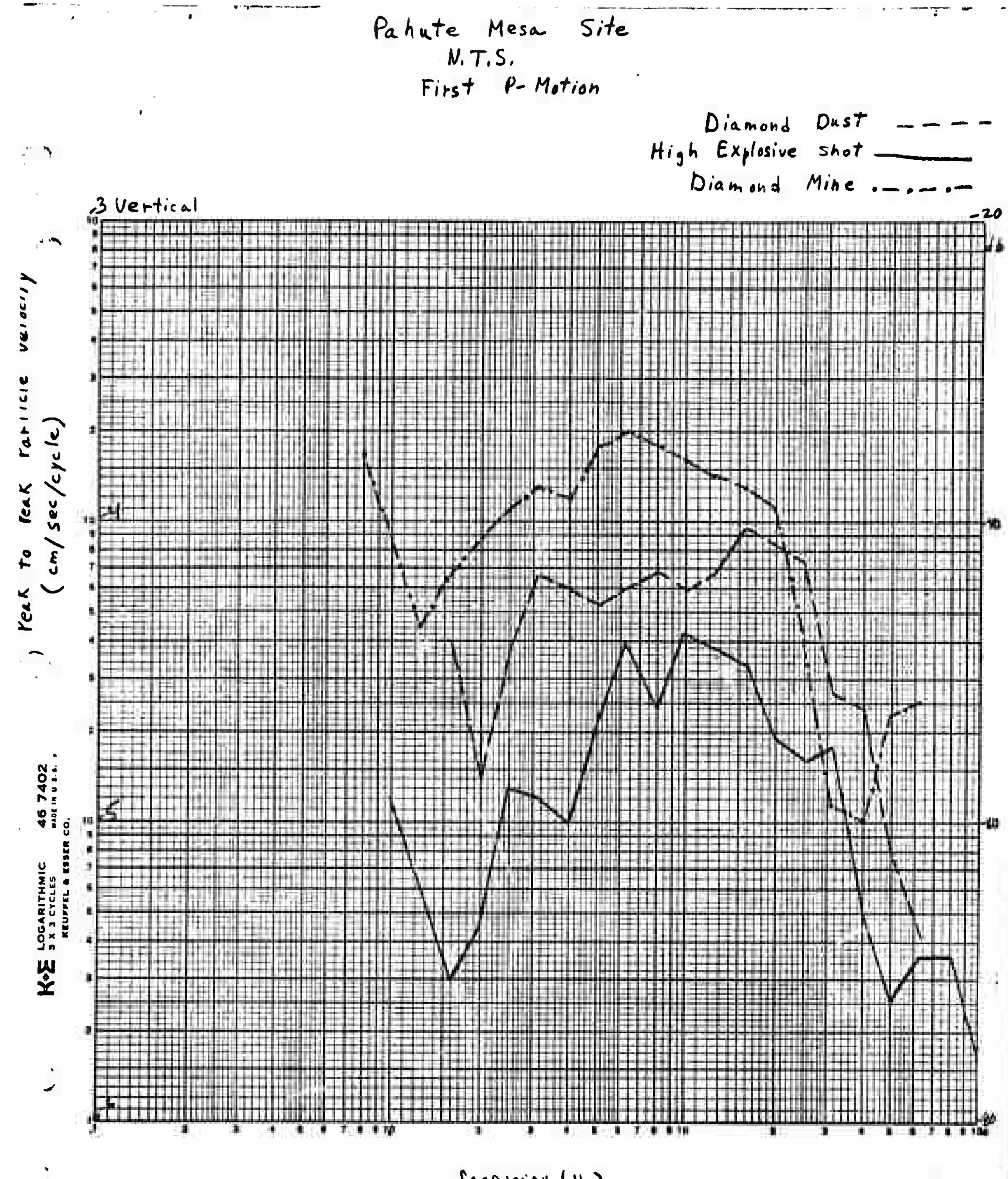

Figure 2-5. Pahute Mesa Site, NTS, First P Motion

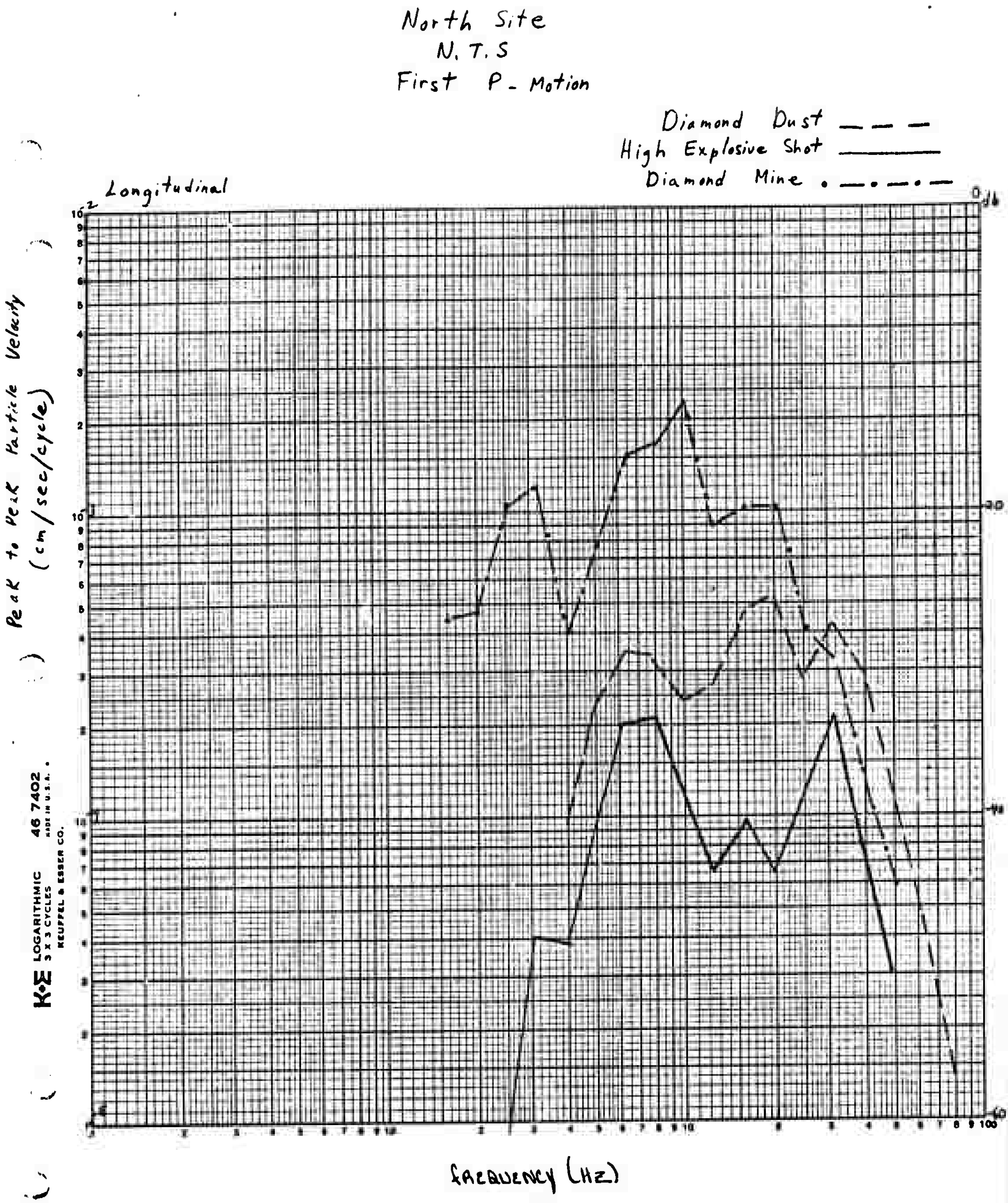

Figure 2-6. North Site, NTS, First P Motion

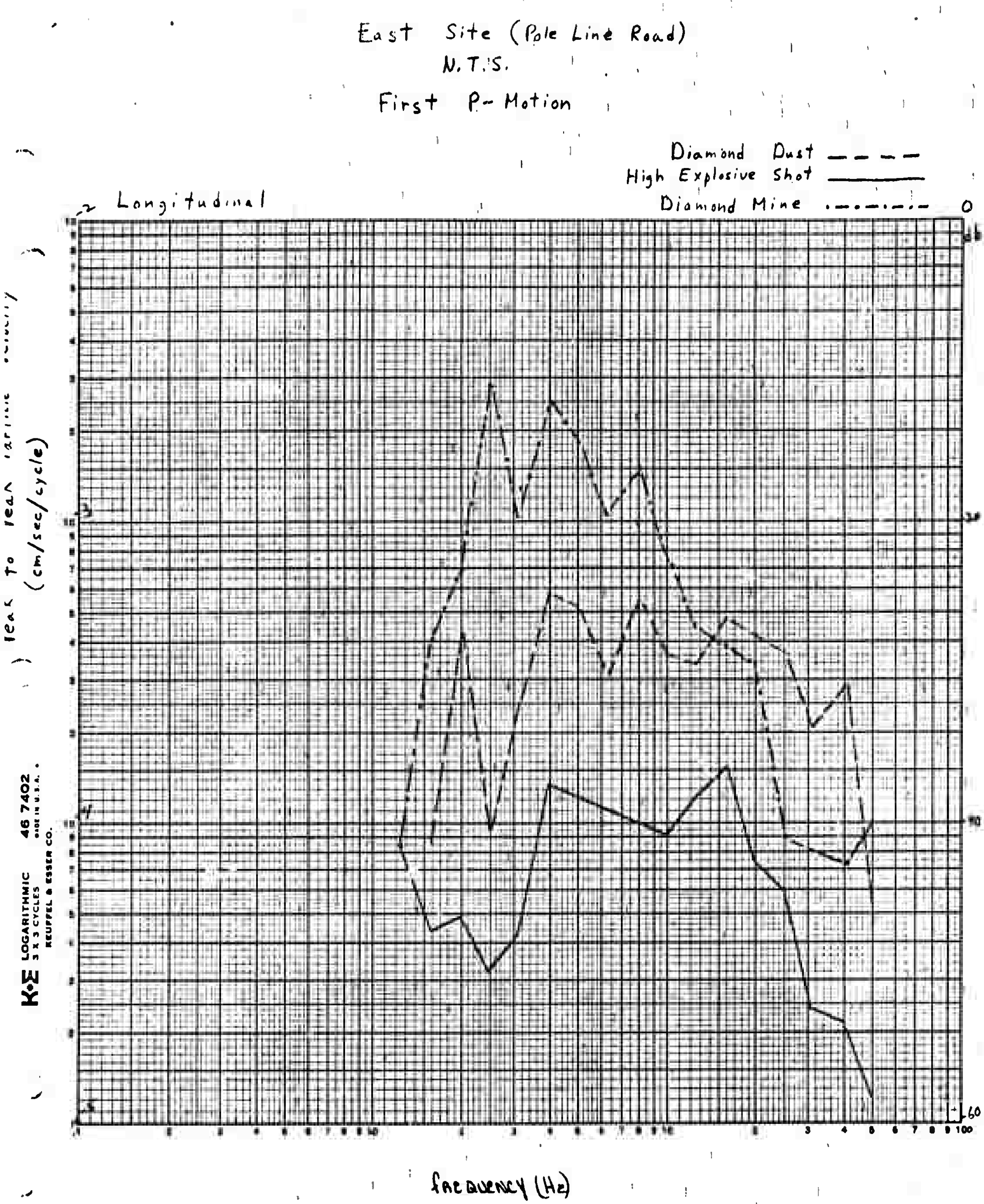

Figure 2-7. East Site (Pole Line Road), NTS, First P Motion

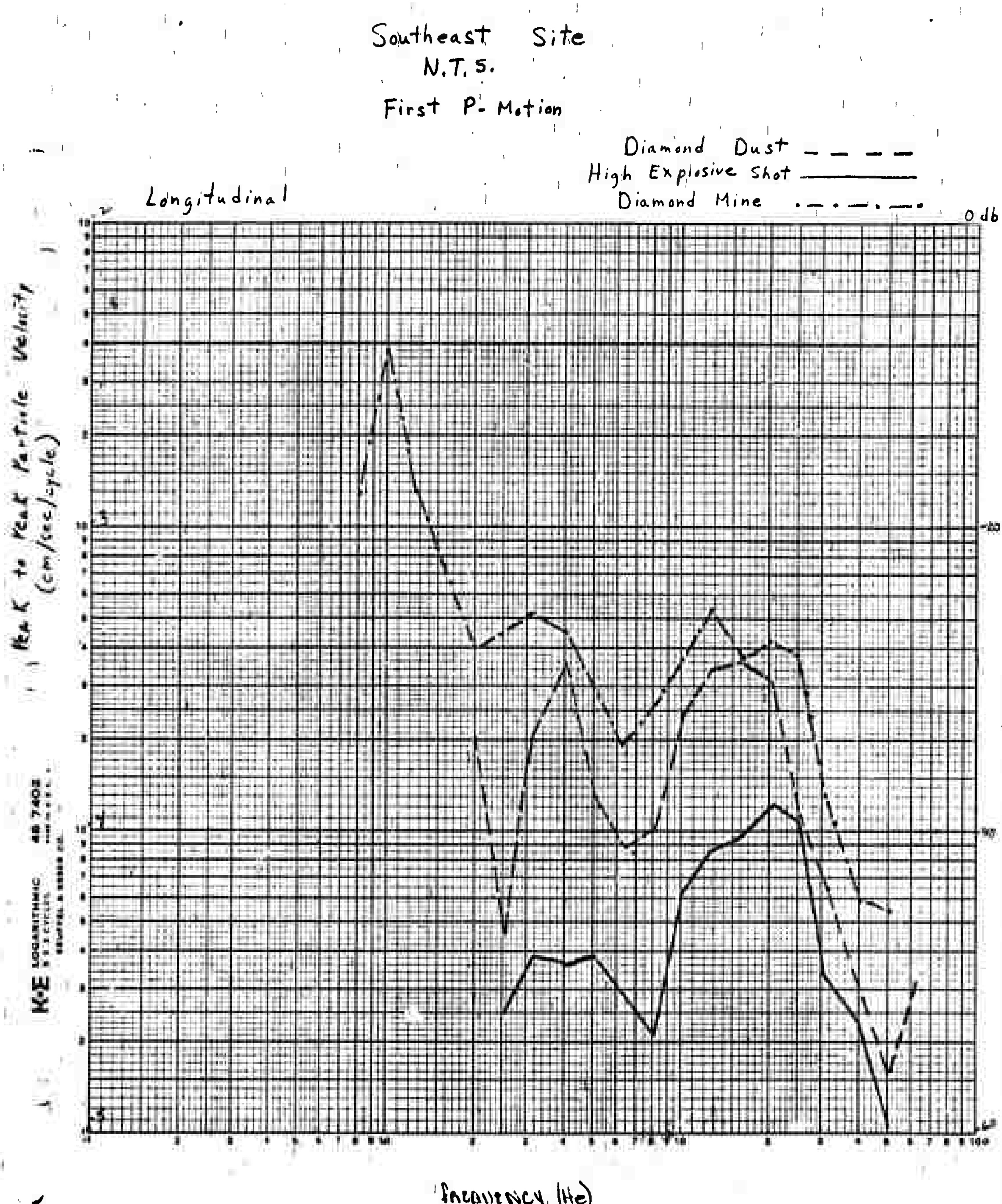

Figure 2-8. Southeast Site, NTS, First P Motion

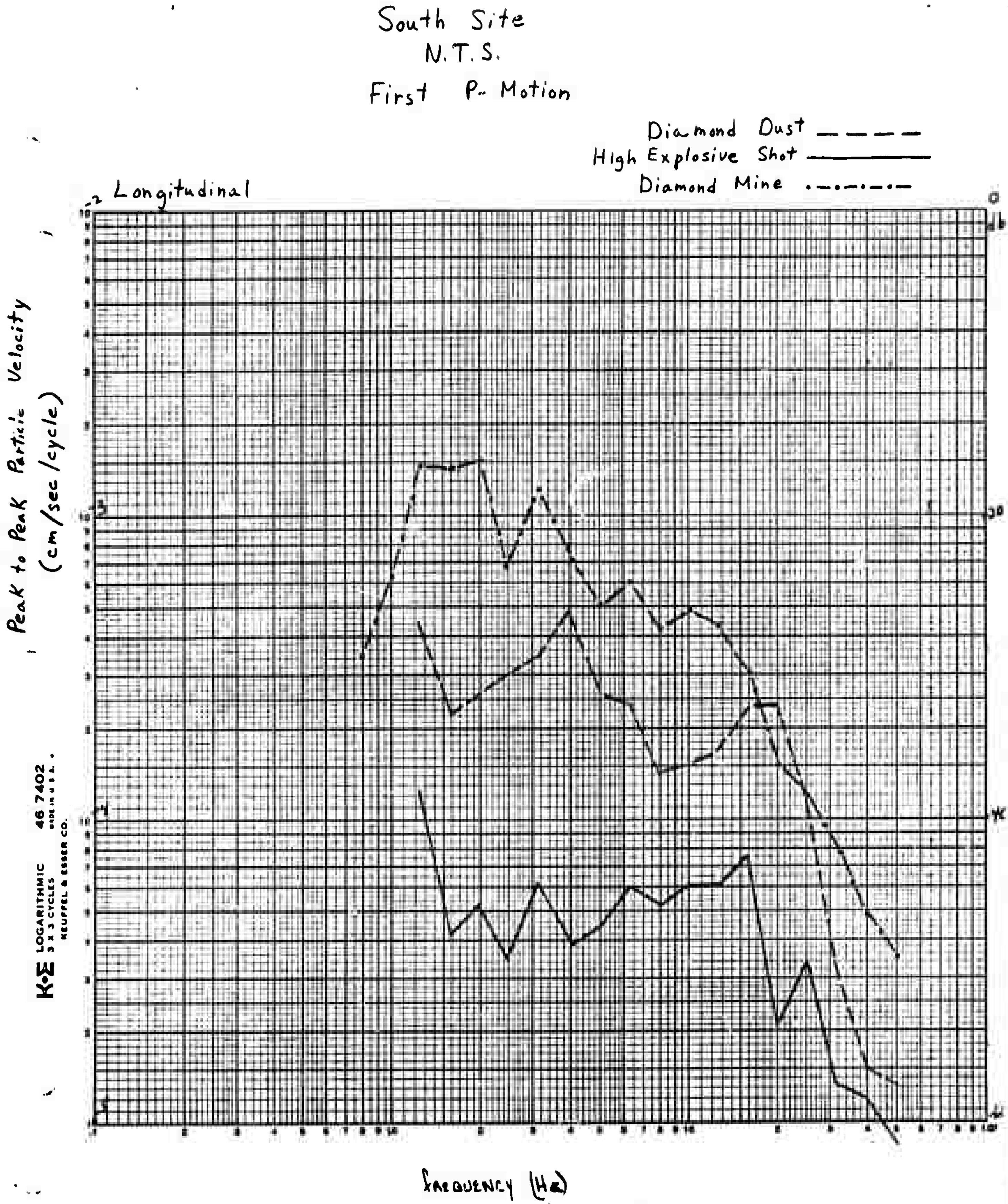

Figure 2-9. South Site, NTS, First P Motion

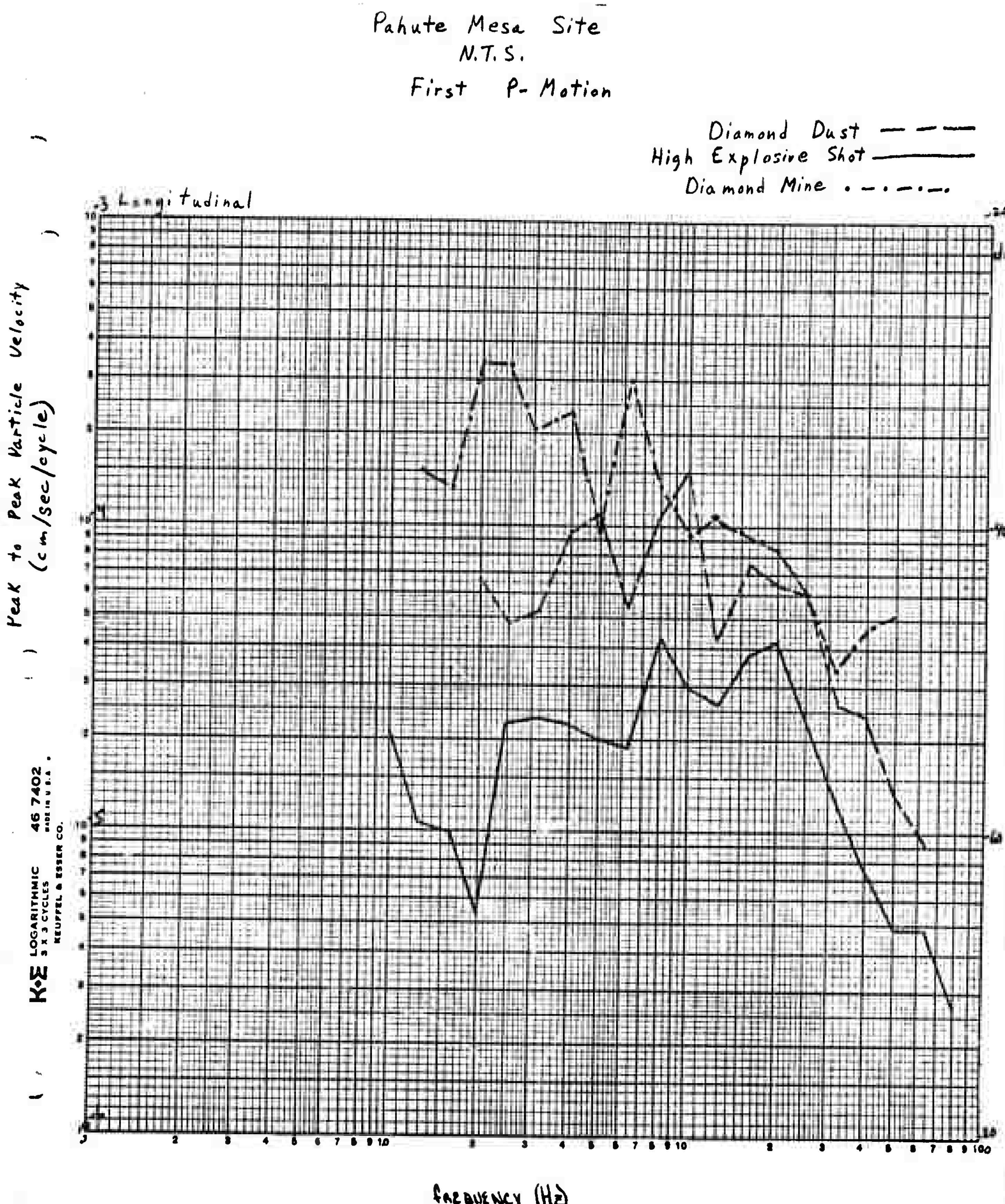

Figure 2-10T Pahute Mesa Site, NTS, First P Motion

DIAMOND MINE in the upper part of the spectrum. The character of the seismograms (wave shapes and phases) between the two DIAMOND events was very similar but appeared to be quite different for the HE shot. The seismograms for DIAMOND MINE appear in Appendix A as figures A-1 through A-5, and the seismograms for the HE event appear as figures B-1 through B-5 in Appendix B. The vertical component in figure A-3 which shows the seismogram from the southeast 2.5 km site may be seen to be small in amplitude and duration as well as lacking in low frequency response. Subsequent investigation revealed that particular seismometer to be partially inoperative. The spectral curves and composite curves, therefore, do not show any vertical data for the southeast site since we consider the data to be invalid.

The spectral curves for DIAMOND MINE are shown in Appendix C as figures C-1 through C-14, and the spectral curves for the HE event are shown in Appendix D as figures D-1 through D-15.

The asymmetries in frequency content and amplitude noted on DIAMOND DUST were also observed for the two additional shots with the notable exception that DIAMOND MINE did not generate the large spectral peaks at 30-40 Hz on the north 2 1/2 km station. This may be due to a non-uniform action of the carbon striking the cavity wall on DIAMOND DUST.

Spectral ratios (DIAMOND MINE/DIAMOND DUST) for the vertical and longitudinal components of the first compressional wave arrival at the five stations are shown in figures 2-11 and 2-12. These curves show a general increase in ratio with decreasing frequency. The average ratio at 10 Hz is approximately +7 to +8 db (a factor of 2.2 to 2.5) and is +10 to +15 db (a factor of 3.2 to 5.6) at 2 Hz.

Figure 2-13 shows the DIAMOND MINE/DIAMOND DUST ratio of the first compressional wave arrival for the transverse component. The same general tendency is shown here although the data is more scattered. Figures 2-14 through 2-19 depict spectral ratios for the two events in each of the three components for two additional wave types--the maximum compressional

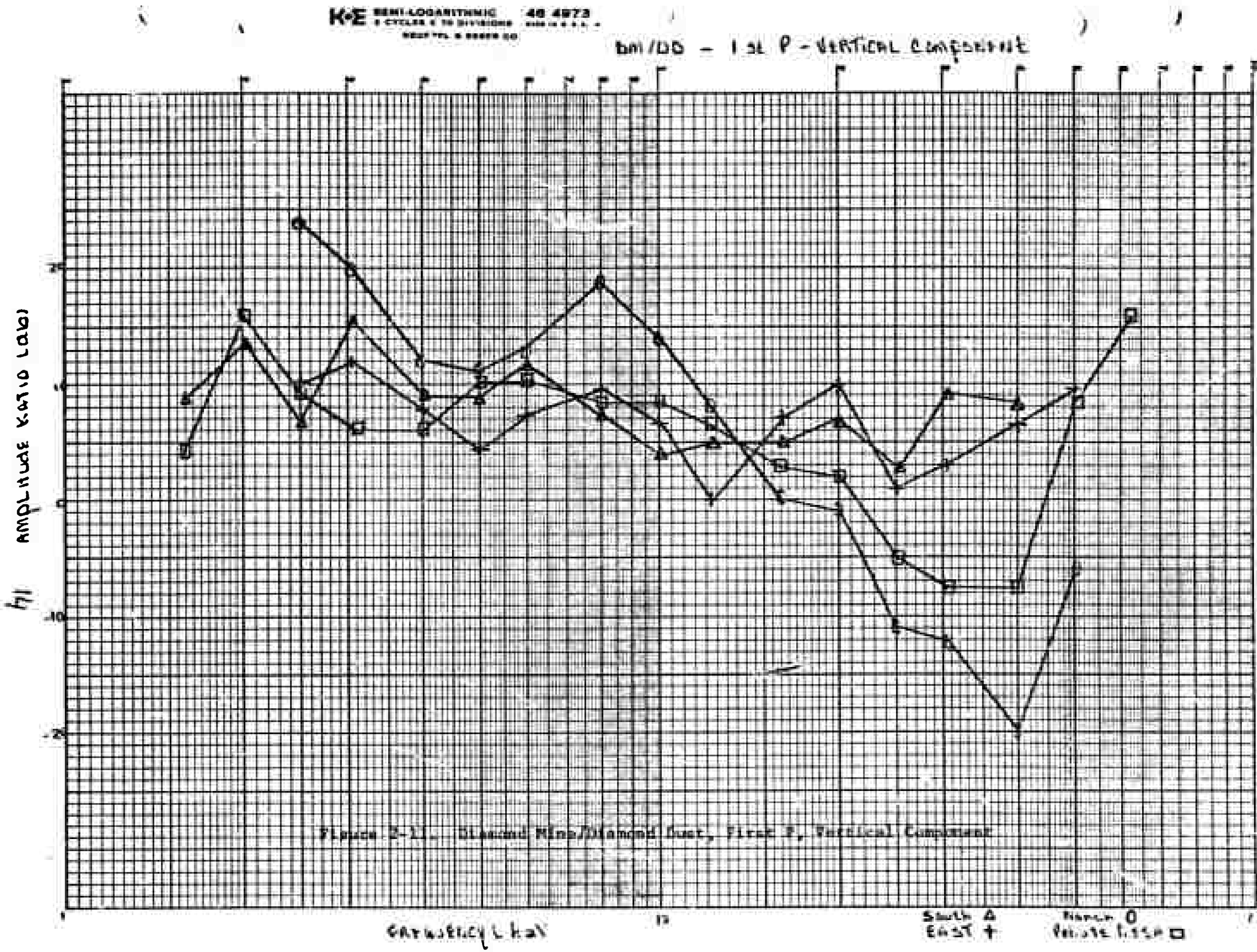

Figure 2-11. Diamond Mine/Diamond Dust, First P, Vertical Component

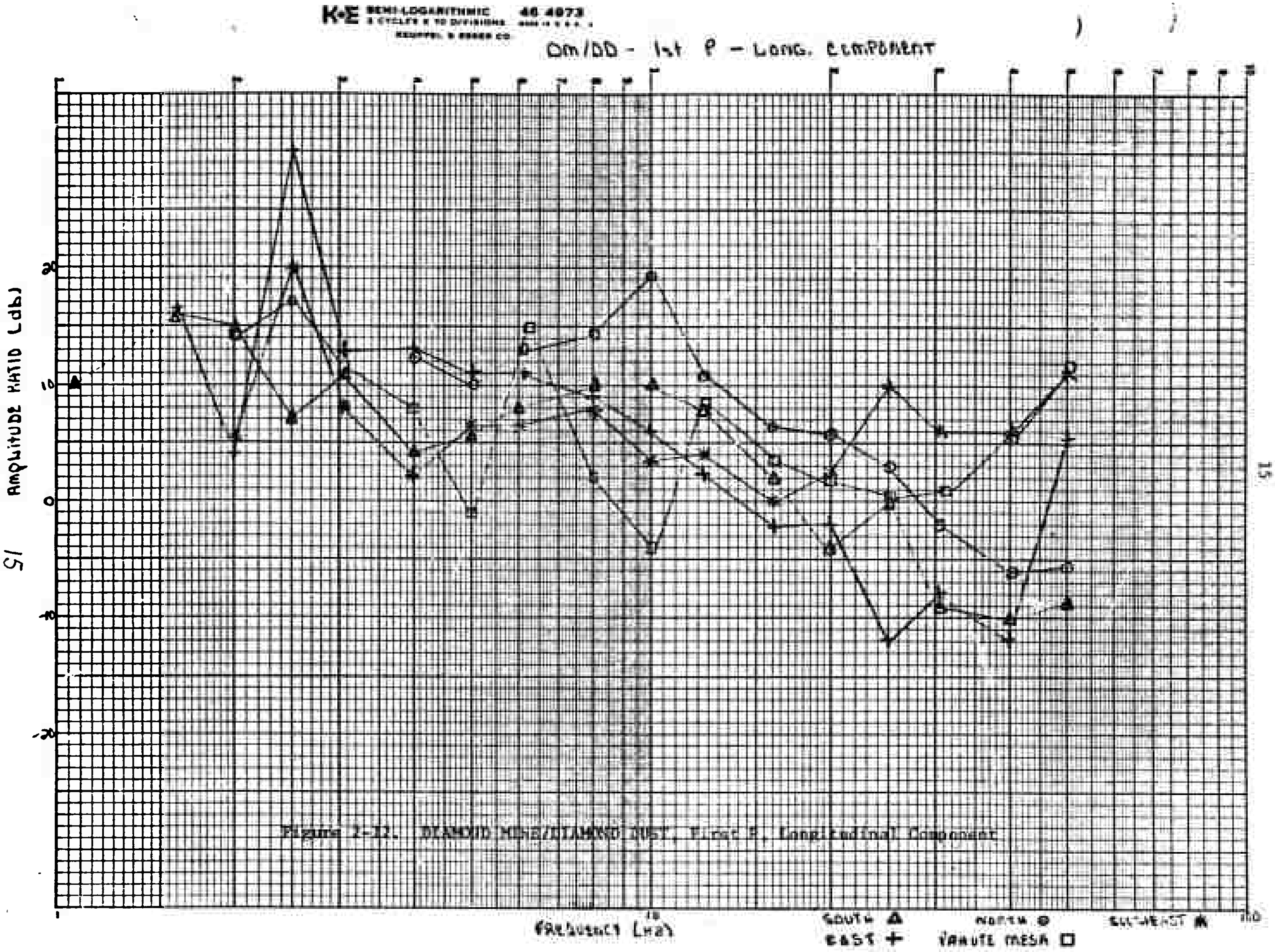

Figure 2-32. DIAMOND MINE/DIAMOND DUST, First P, Longitudinal Component

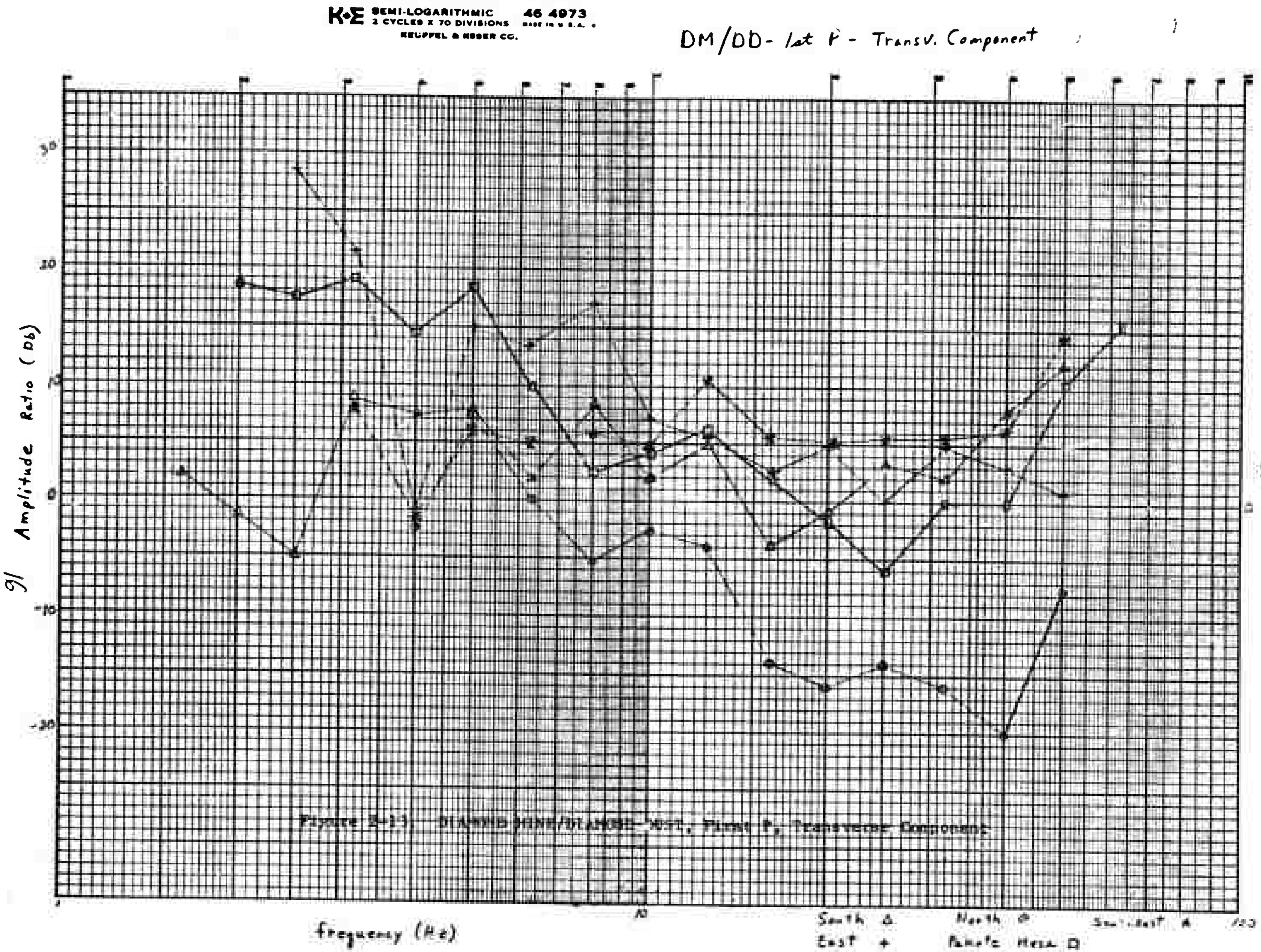

Figure 2-13. DIAMOND MINE/DIAMOND DUST, First P, Transverse Component

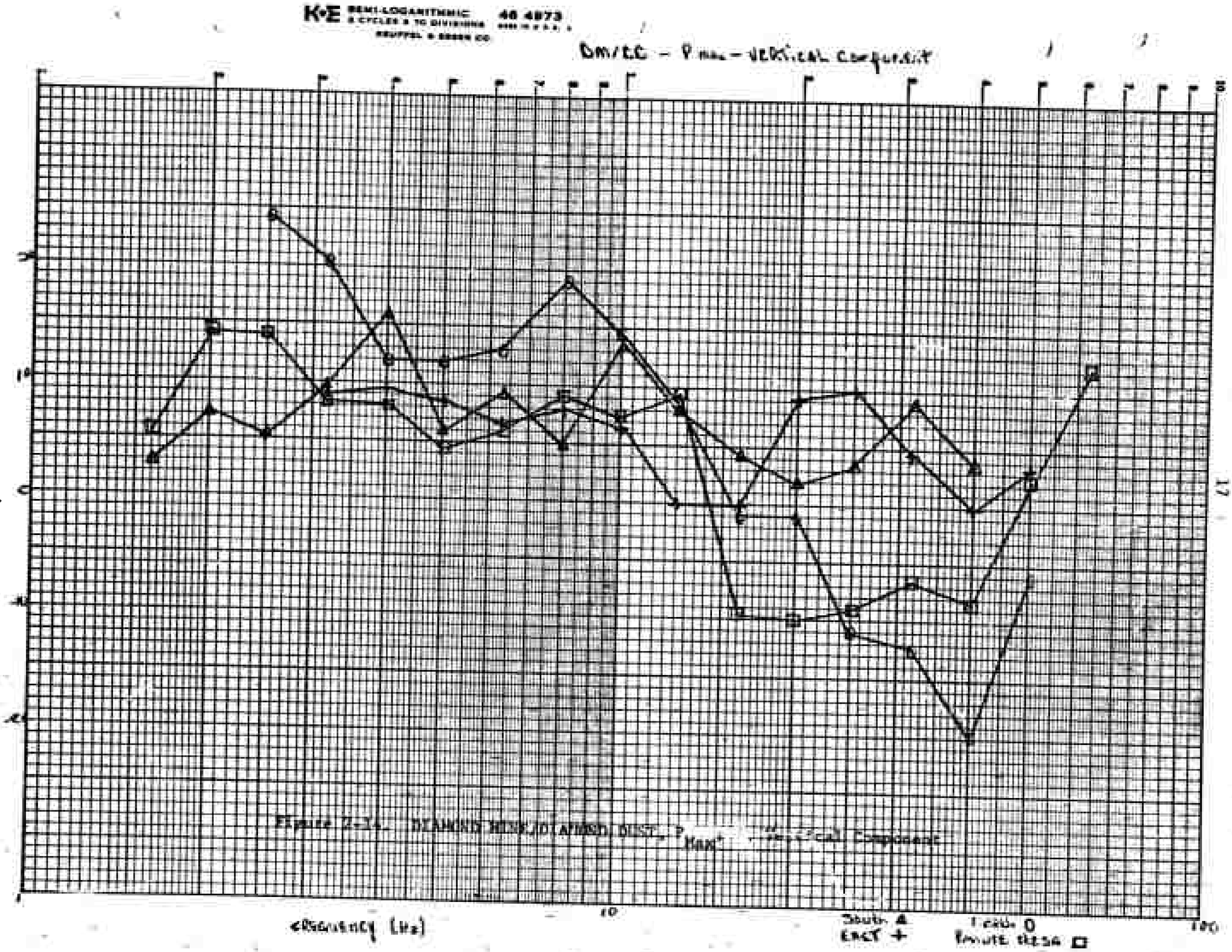

Figure 2-14. DIAMOND MINE/DIAMOND DUST, P_{MAX}, Vertical Component

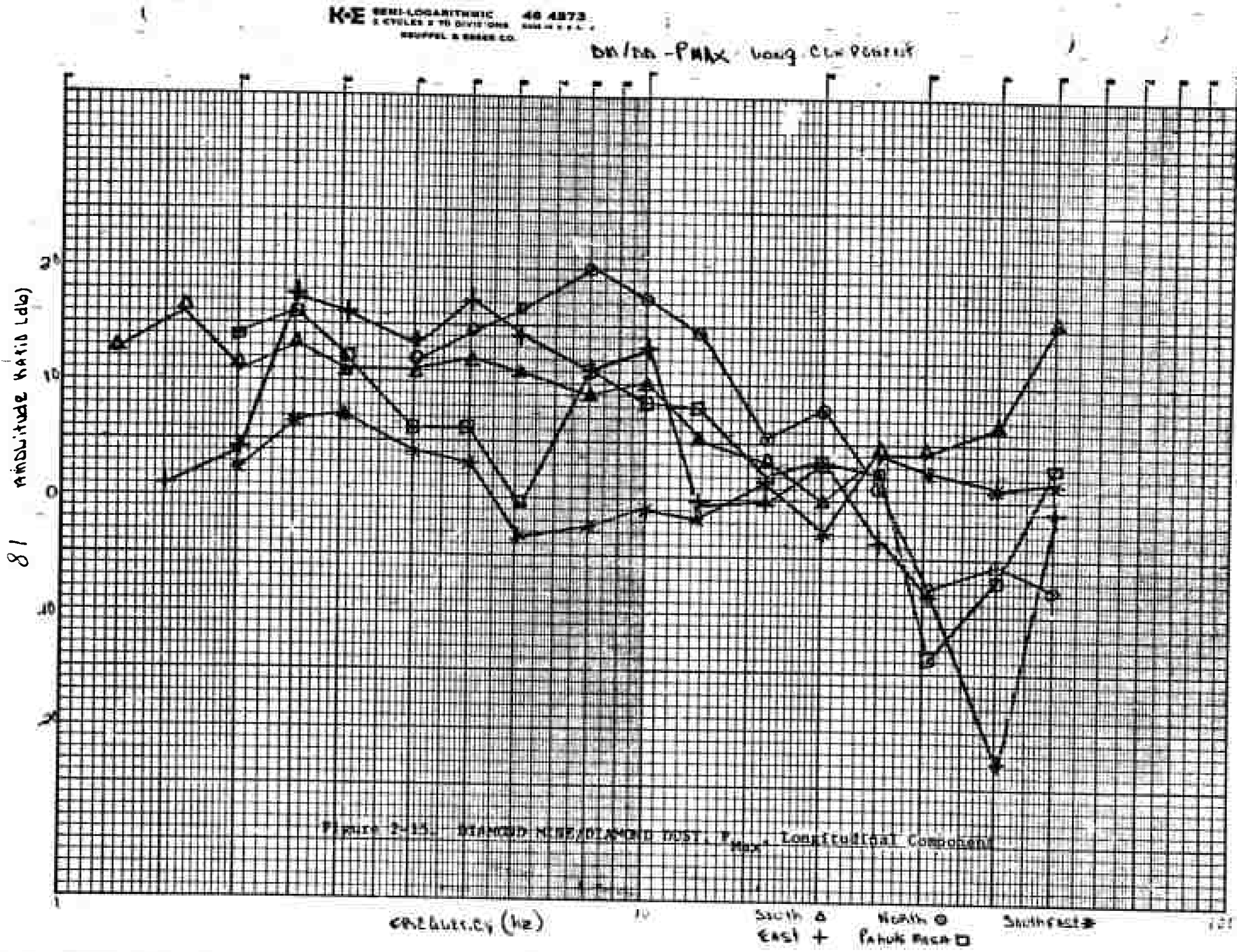

Figure 2-15. DIAMOND MINE/DIAMOND DUST, P_{Max} - Longitudinal Component

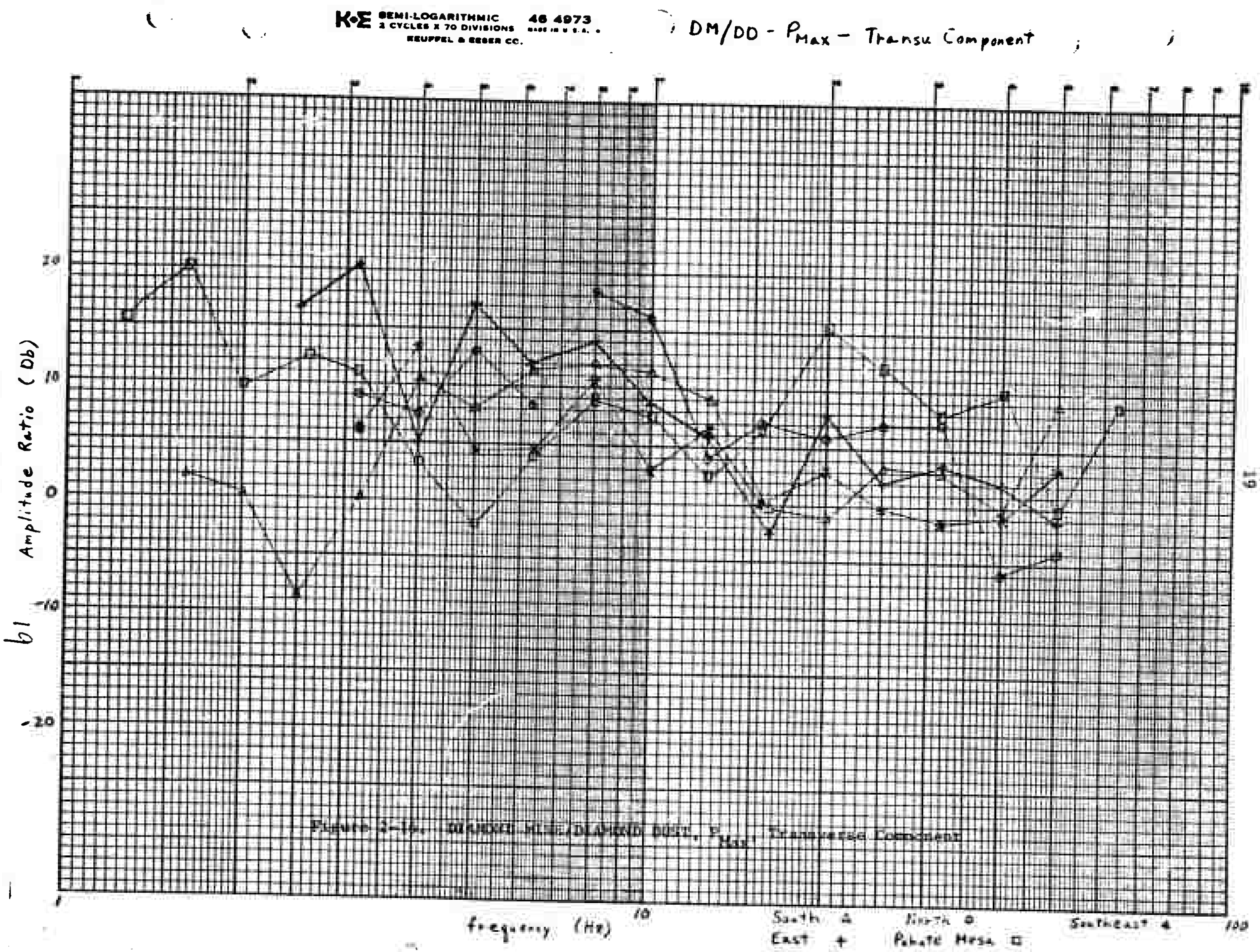

Figure 2-16. DIAMOND MINE/DIAMOND DUST, P_{Max}, Transverse Component

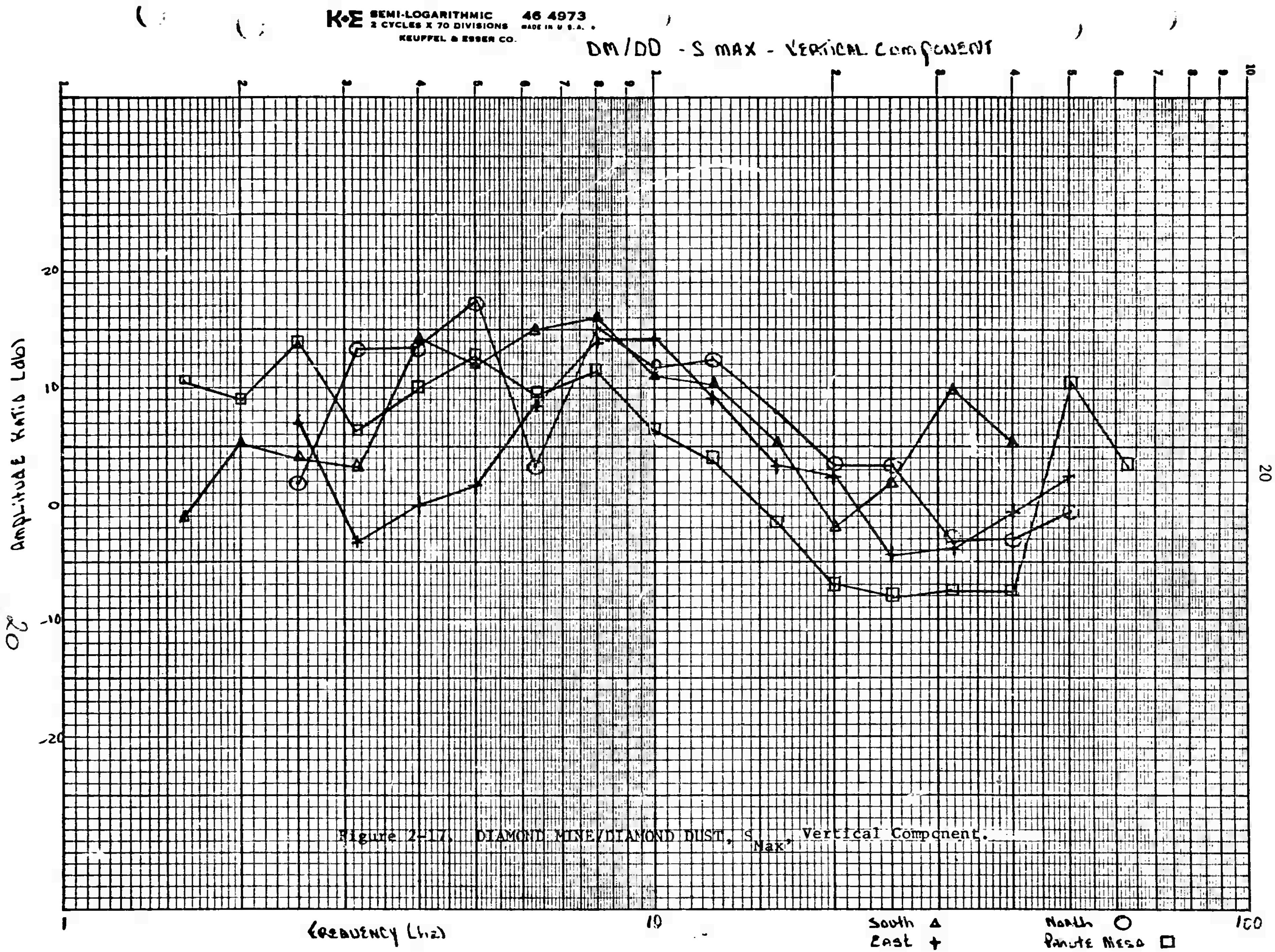

Figure 2-17. DIAMOND MINE/DIAMOND DUST, S_{Max}, Vertical Component.

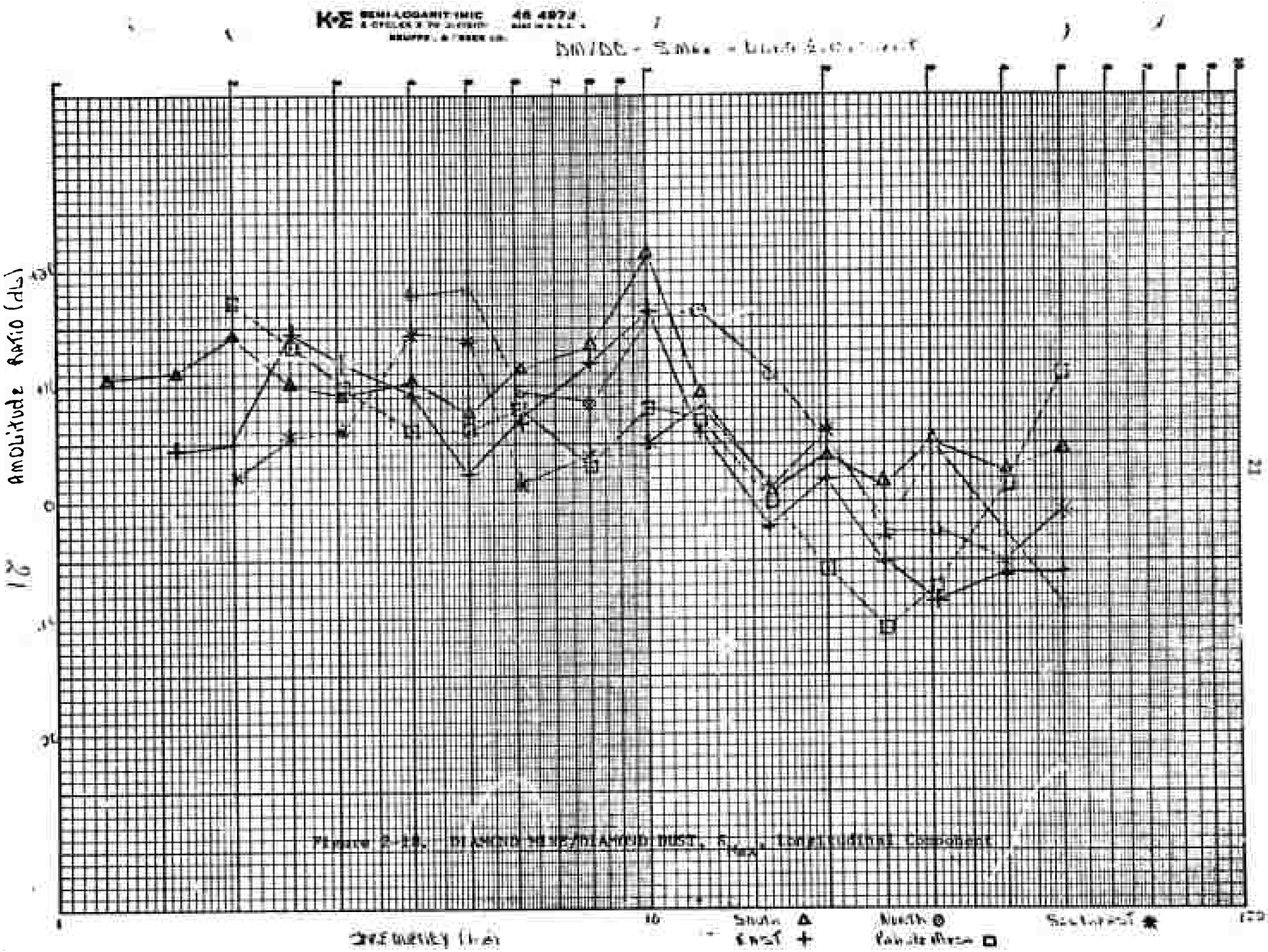

Figure 2-28. DIAMOND MINE/DIAMOND DUST, R_{max}, Longitudinal Component

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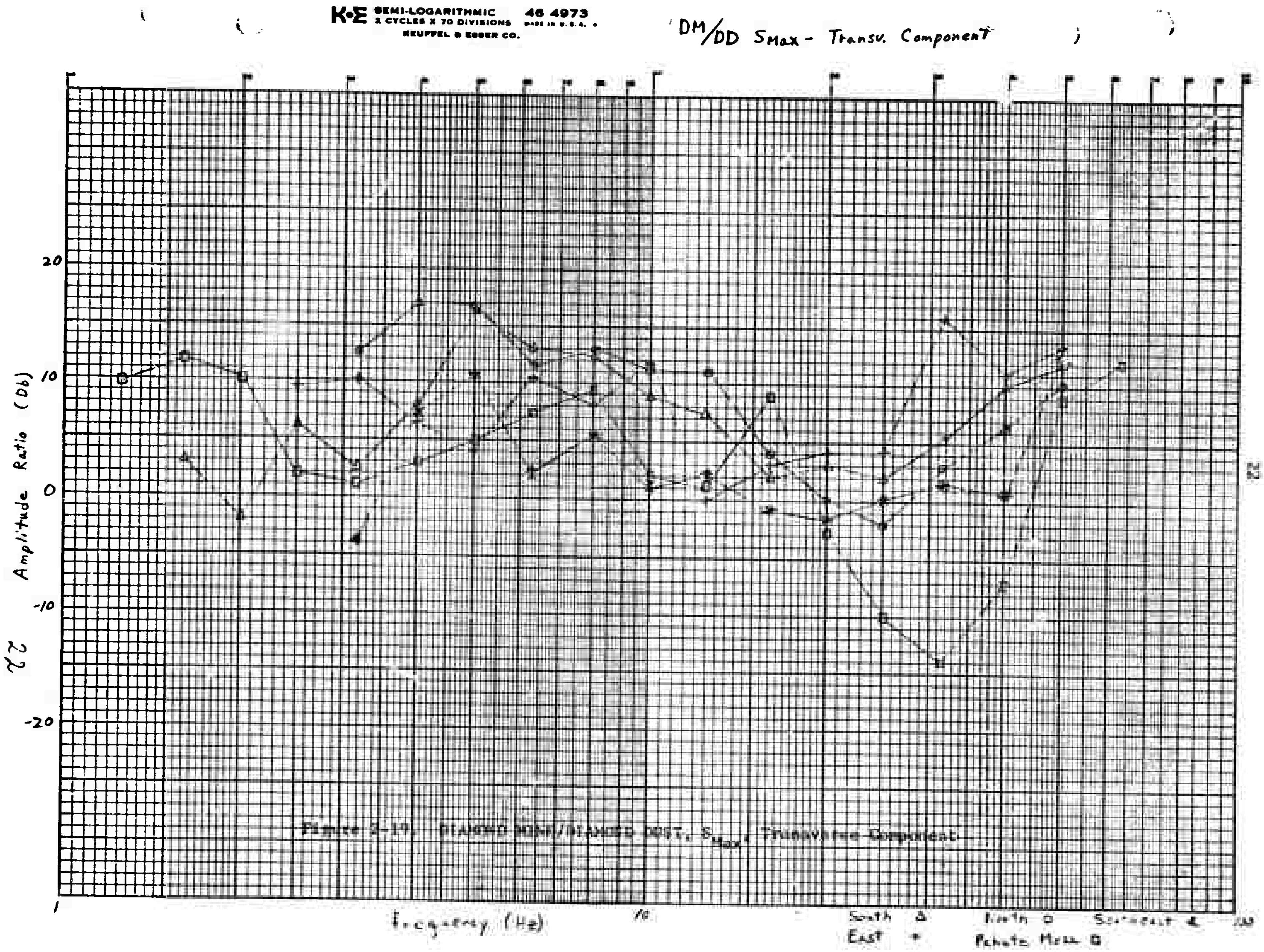

Figure 2-19. DIAMOND MINE/DIAMOND DUST, S_{Max}, Transverse Component

wave, and the maximum shear wave. The same increase in signal ratio with decreasing frequency may be seen in all of these plots.

A comparison of the broadband signal levels on the seismograms for the three events on each of the five three-component stations showed that DIAMOND MINE averaged a factor of 1.6 (ranged up to 2.5) larger than DIAMOND DUST and that the latter averaged a factor of 2.5 larger than the HE shot. The fact that the broadband seismograms give smaller amplitude ratios than the spectral ratios shown in figures 2-11 through 2-19 can be explained by the fact that DIAMOND MINE and DIAMOND DUST have different spectral peaks and the amplitudes measured on the seismograms would reflect these spectral peaks. For decoupling purposes, the lower frequency spectral ratios are considered the most significant since the attenuation of the higher frequency energy would remove any differences in the high frequency signals at teleseismic distances.

The lower frequencies observed at the south and southeast stations may be due in part to the shattered zones of the previous larger shots fired in Area 16. This is illustrated in figure 2-20 (from Whitener, 1971). It can be seen that the propagation paths to these two stations, especially to the south site, traverses the cracked regions of Double Play, Gum Drop, and Marshmallow. One would anticipate that this would cause greater attenuation of the high frequency energy propagating through this region. At a frequency of 10 Hz, the compressional waves would have wavelengths of the order of 700 ft and at 20 Hz approximately 350 ft. Hence, the shattered region represents significant portions of a wavelength for the high frequency energy.

2.2. DATA AVAILABLE FROM THE NEVADA SEISMOGRAPH NET

A network of seismograph stations are deployed in the southern portion of Nevada and adjacent areas. These stations are operated by the U.S.G.S. National Center for Earthquake Research, NOAA/ERL Special Projects Group at LasVegas, Sandia Laboratories, and Lawrence Livermore Laboratories.

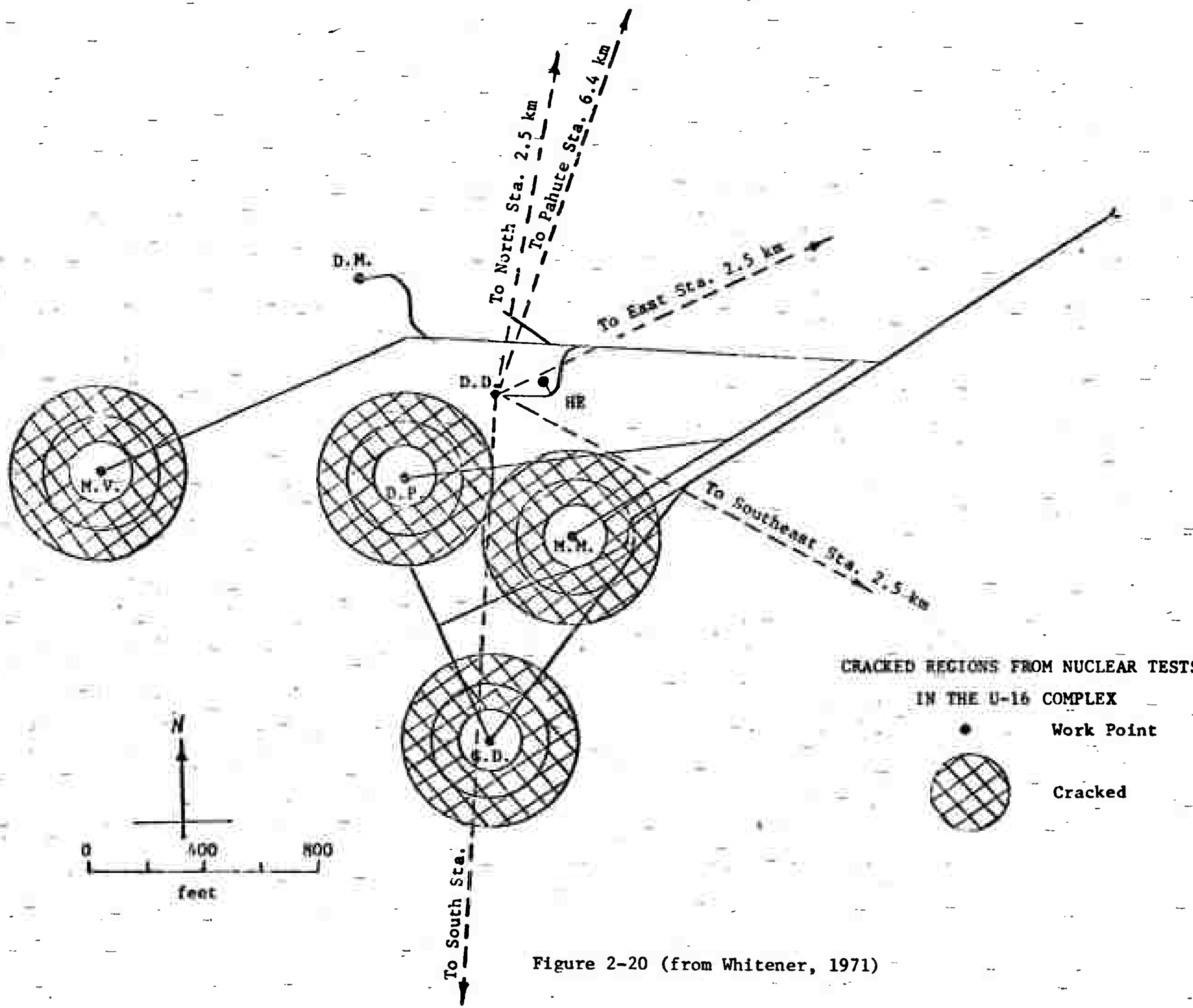

Figure 2-20 (from Whitener, 1971)

All of these stations are recorded on Develacorder systems. Fourteen of these stations (Pahute Mesa area) are recorded on the USGS/NCER NTS net. This network was designed to monitor small magnitude natural earthquakes occurring in the NTS area and runs with more or less fixed gain (the gains are not adjusted to record nuclear events). The network is also recorded on magnetic tape. (The tapes are only retained for about a week unless significant events are recorded.) The second Develacorder system operated by the USGS/NCER is the CNTS net and is composed of five USGS stations, four LLL stations, and seven stations in Texas. The third Develacorder system is operated by the NOAA/ERL Special Projects Group and is composed of eleven of their own stations, six Sandia stations, and six USGS stations. The Sandia stations are also recorded on magnetic tape by Sandia for specific shots. Part, if not all, of the NOAA/ERL stations are also recorded on Helicorders. They have the capability of also recording on magnetic tape.

The Develacorder system is an automatic recording system where the seismic data is recorded on 16 mm film. The Helicorder is a direct writing system which employs a pressure sensitive paper.

Trips were made to the USGS-Menlo Park, NOAA/ERL-LasVegas, and to Sandia to discuss their data and to obtain copies of seismograms for the following events.

DIAMOND DUST
DIAMOND MINE
HE Shot of 2/4/71
HE Shot of 4/29/71 (MINE THROW)
HE Shot of 5/28/71
HE Shot of 6/15/71

These agencies cooperated fully and copies were obtained of the available data. A listing of the stations in the Nevada Seismograph Net is contained in Table A along with their coordinates and approximate distance from DIAMOND DUST/MINE. A more detailed listing is shown in Table B for the stations of the NOAA/ERL CGS Net. A map of the latter is also shown in figure 2-21.

*NTS Net
†CNTS Net
+CGS Net

TABLE A

STATION DISTANCE AND AZIMUTH
FROM THE POINT 37.0104N, 116.2019W

L	STATION	LAT N (DEG MIN)	LONG W (DEG MIN)	DISTANCE (KM)	AZIMUTH
1	NT11*	37 16.70	116 26.20	36.3	325.1
2	NT12*	37 13.78	116 26.81	32.6	318.4
3	NT13*	37 9.42	116 40.04	44.4	291.7
4	NT14*	37 8.66	116 15.79	15.9	340.0
5	NT15*	37 13.58	116 30.40	36.1	311.7
6	NT16*	37 5.55	116 18.96	13.6	312.1
7	NYNC*	37 8.50	116 5.27	17.8	34.7
8	NYND*	37 7.96	116 5.88	16.4	34.1
9	NT18*	37 25.76	116 23.52	49.5	340.2
10	NT19*	37 17.00	116 18.30	31.7	343.3
11	NT20*	37 25.37	116 33.88	56.0	325.1
12	NT21*	37 22.51	116 26.05	45.5	333.2
13	N222*	37 12.81	116 18.94	24.7	336.0
14	NT23*	37 18.08	116 36.97	48.9	311.5
15	NT24*	37 17.18	116 30.87	41.3	318.0
16	NRSR	37 18.50	117 24.88	112.5	287.5
17	NRGM	37 31.60	115 48.10	67.4	31.6
18	NRUB	36 53.48	117 30.24	116.5	263.9
19	NRCP†	37 44.99	116 52.05	101.1	324.6
20	DFOD†	37 33.18	117 45.16	149.9	294.2
21	NRCE†	37 43.68	116 18.64	80.4	353.2
22	NRWP†	37 56.75	115 37.75	115.6	25.7
23	LAN †	34 23.39	116 24.69	292.0	183.8
24	ELK †	40 44.69	115 14.33	423.5	11.1
25	KAN †	37 1.00	112 49.35	300.0	88.8
26	MIN †	38 25.93	118 9.26	233.4	313.2
27	NRGF†	37 40.86	117 14.75	118.6	309.3
28	NYCH+	37 9.30	116 9.32	16.6	14.4
29	NYJT+	37 .48	115 58.48	20.2	90.7
30	NYMC+	37 13.88	116 3.14	27.9	28.3
31	NYRS+	37 3.32	116 5.50	11.0	62.9
32	NYSR+	37 1.95	116 10.13	3.8	50.1
33	NYVN+	37 6.77	115 59.40	22.0	58.7
34	ALA +	37 14.50	115 6.90	99.7	74.7
35	BMN +	40 25.89	117 13.31	390.5	347.2
36	BTY +	36 53.00	116 46.00	52.1	254.4
37	CPX +	36 55.92	116 3.33	15.7	123.8
38	DAC +	36 16.62	117 35.62	148.5	237.1
39	ELY +	39 7.88	114 53.52	262.2	25.5
40	ETS +	36 49.95	116 18.52	21.9	205.7
41	LEE +	37 14.58	113 22.60	251.8	83.3
42	LSM +	36 44.32	116 16.32	30.9	191.7
43	LVN +	36 6.55	115 8.40	138.0	136.3
44	MCV +	36 38.01	115 59.99	45.6	156.7
45	NEL +	35 42.74	114 50.61	188.7	139.5
46	SMN +	37 8.60	116 46.00	52.2	286.6
47	TPH +	38 4.48	117 13.35	148.6	323.1
48	NT17	37 8.57	116 23.14	22.0	312.1
49	NRGP†	37 20.45	117 22.75	110.6	289.8

TABLE B

NOAA/ERL SEISMOGRAPH STATIONS

Station	Abbr.	Medium	North Latitude	Longitude	Elev. Ft.	Approx. Sens. at 1 Hz.
Alamo	ALA	Hardrock	37°14.5'	115°06.9'	3500	100K
Beatty	BTY	Hardrock	36°53.0'	116°46.0'	3380	100K
Boulder City	BCN	Hardrock	35°58.9'	114°50.0'	2530	80K
CP-1	CPX	Hardrock	36°55.9'	116°03.3'	4215	55K
Engine Test Stand	ETS	Alluvium	36°49.95'	116°18.5'	3800	0.1K
Eureka	EUR	Hardrock	39°29.0'	115°58.2'	7130	260K
Las Vegas	LVN	Alluvium	36°06.6'	115°08.4'	2200	8K
Little Skull Mtn.	LSM	Hardrock	36°44.3'	116°16.3'	3760	100K
Mercury	MCV	Hardrock	36°38.0'	116°00.0'	3800	100K
Sleeping Mountain	SMN	Hardrock	37°08.60'	116°46.00'	4087	100K
Twin Springs	TSV	Hardrock	38°12.0'	116°09.0'	5400	100K

SANDIA STATIONS MONITORED BY NOAA/ERL

Station	Abbr.	Medium	North Latitude	Longitude	Elev. Ft.	Approx. Sens. at 1 Hz.
Battle Mountain	BMN	Hardrock	40°25.9'	117°13.3'	5000	Variable
Darwin	DAC	Hardrock	36°16.6'	117°35.6'	4700	Variable
Ely	ELY	Hardrock	39°07.9'	114°53.5'	6600	Variable
Leeds	LEE	Hardrock	37°14.6'	113°22.6'	3500	Variable
Nelson	NEL	Hardrock	35°42.7'	114°50.6'	3450	Variable
Tonopah	TPH	Hardrock	38°04.5'	117°13.4'	6200	Variable

USGS STATIONS MONITORED BY NOAA/ERL

Station	Abbr.	Medium	North Latitude	Longitude	Elev. Ft.	Approx. Sens. at 1 Hz.
Charley, Nev	NYC		37°09.32'	116°09.32'	5166	Not Known
Climax Mine, Nev	NYM		37°13.88'	116°03.14'	4886	Not Known
Joshua Tree, Nev	NYJ		37°00.48'	115°58.48'	3920	Not Known
Receiver Site, Nev	NYR		37°03.32'	116°05.50'	3898	Not Known
Syncline Ridge, Nev	NYS		37°01.95'	116°10.13'	4599	Not Known
Vern, Nev	NYV		37°06.77'	115°59.40	4395	Not Known

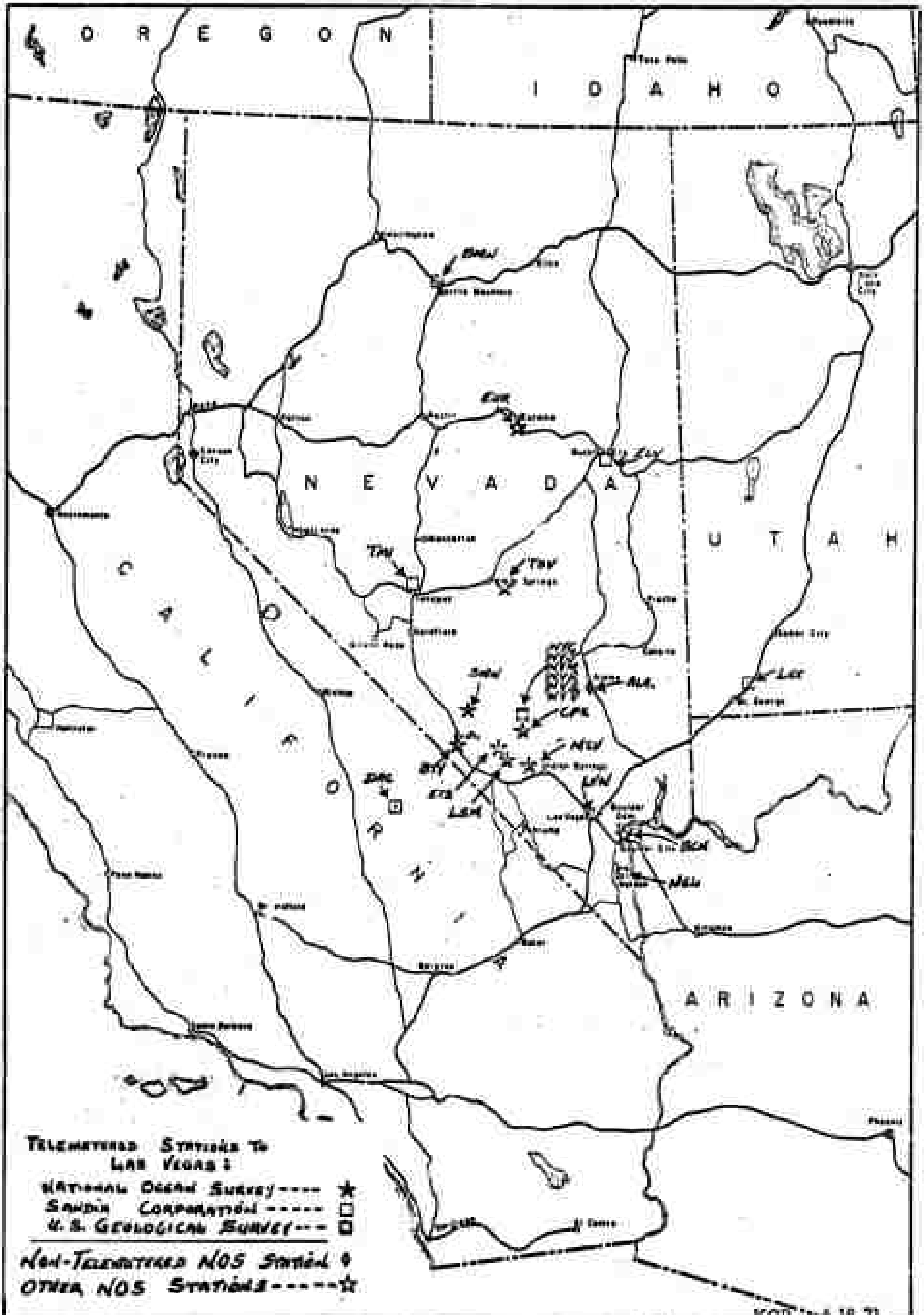

Figure 2-21. NOAA/ERL CGS Net

Analyses of these data have not been completed. However, average magnitudes have been determined and will be discussed in the next section.

The amount of usable data from these shots and the quality of the data are summarized in Tables C, D, and E. The fact that more usable data is not available from these stations should not be viewed critically since these shots were quite small and the stations were not established for the purpose of monitoring small yield shots.

Data from previous shots in Area 16 are tabulated in Table F (obtained from Tendall, 1971). These shots include MARSHMALLOW, GUMDROP, DOUBLE PLAY, and MING VASE with yields in the range of approximately 275 to 375 larger than DIAMOND MINE/DUST. These data will be very useful in correlating the results of MINE DUST which should be recordable at these distances if the record gain is high enough and the background noise levels are low enough.

DIAMOND MINE and DIAMOND DUST were both recorded at the Beatty station located approximately 52 km west-southwest of ground zero. Trace amplitudes measured on Helicorder records for this station were a factor of 2.6 larger for DIAMOND MINE. Three stations of the CGS net recorded DIAMOND MINE on Helicorders. Considerable variation in signal level was seen on these recordings. This is illustrated below:

Station	Distance	Bearing	Maximum Trace Amplitude Normalized to Gain of 102 db
BTY	52.2	W-SW	26 mm_{pp}
LSM	30.8	S-SW	21 mm_{pp}
MCV	45.5	S-SE	5 mm_{pp}

This azimuthal variation is a factor of five and may correlate in part to the fracturing of the area around the source due to previous higher yield shots.

TABLE C

SUMMARY OF AVAILABLE DATA FROM NEVADA SEISMOGRAPH NET
FOR DIAMOND DUST

A. USGS/NCER NTS Seismograph Net

Station	Record Quality	Distance from DIAMOND DUST (km)
NT11	Very low signal level	36.3
NT12	Hardly detectable	32.6
NT13	Good	44.4
NT14	High signal level 1st P O.K.	15.9
NT16	Good	13.7
NT18	Usable	49.0
NT20	Very low signal level	56.0
NT22	High signal level	24.7
NT23	Low signal level	48.9

B. USGS/NCER CNTS Seismograph Net

No signal was detected at any station.
(Note--The location of all of these stations with the exception of DFOD was changed in October 1970).

C. NOAA/ERL CGS Seismograph Net

Not yet in operation at the time of this shot. However, some stations were recording on Helicorders.

BTY	Good (Helicorder recording)	52.1

TABLE D

SUMMARY OF AVAILABLE DATA FROM NEVADA SEISMOGRAPH NET FOR DIAMOND MINE

A. USGS/NCER NTS Seismograph Net

Station	Record Quality	Distance from DIAMOND MINE (km)
NT14	Overrecorded-1st P O.K.	15.9
NT16	Poor (high noise)	13.7
NT18	High noise-1st P appears too late*	49.5
NT20	High noise*	56
NT21	Good*	45.5
NT22	Low frequency late P*	24.7

B. USGS/NCER CNTS Seismograph Net

NRGF	Good †	118.6
NRWP	Good	115.6
NRCP	Low signal level	101.0

C. NOAA/ERL CGS Seismograph Net

BTY	Good	52.1
LSM	Good	30.8
SMN	Low	52.2
NYC	Overrecorded	16.6
NYJ	Overrecorded	20.2
NYM	Noisy	27.9
NYR	Good	11.0
NYS	Overrecorded	4.0
NYV	Noisy	22.0

(Helicorder records are available for BTY, LSM, & MCV.)

*Arrival times would indicate that these stations are misidentified. Will verify.

†First arrival appears late.

TABLE E

SUMMARY OF AVAILABLE DATA FROM NEVADA SEISMOGRAPH NET
FOR
HIGH EXPLOSIVE SHOT OF 4 FEBRUARY 1971

A. USGS/NCER NTS Seismograph Net

Station	Record Quality	Distance From HE Shot (km)
NT13	High signal level	44.4
NT14	Good	15.9
NT16	High	13.7
NT22	Low--questionable	24.7

B. USGS/NCER CNTS Seismograph Net

No signal was detected at any station.

C. NOAA/ERL CGS Seismograph Net

NYC	Questionable	16.6
NYM	Good	27.9
BTY		(Helicorder recording)
LSM		(Helicorder recording)

TABLE F
Amplitude* of Area 16 Events

		6/28/62 MARSHMALLOW	4/21/65 GUMDROP	6/15/66 DOUBLE PLAY	11/20/68 MING VASE
Tonopah 148.5 km NW	V_P =	18.6	19.7	19.6	23.2
	V_S =	19.1	17.9	14.4	21.8
	R_P =	20.5	16.7	25.9	26.5
	R_S =	15	26.7	20.2	31.1
	T_P =	16.3	-	20.3	16.3
	T_S =	21.7	-	17.4	21.1
Darwin 148.4 km SW	V_P =	6.19	4.08	8.8	10.1
	V_S =	6.10	5.14	9.86	8.4
	R_P =	9.45	9.45	Overrecorded	11.25
	R_S =	5.42	4.63	Overrecorded	4.61
	T_P =	4.48	4.77	5.01	-
	T_S =	11.6	9.11	10.2	-
Nelson 188.6 km SE	V_P =	Station not yet in operation for this shot.	5.12	4.8	4.28
	V_S =		5.79	5.92	4.86
	R_P =		5.4	3.72	-
	R_S =		9.4	Overrecorded	-
	T_P =		3.5	2.79	4.29
	T_S =		5.58	Overrecorded	3.83
St. George/ Leeds 251.6 km E	V_P =	Station not yet in operation for this shot.	3.75	2.78	4.74
	V_S =		5.22	5.35	4.76
	R_P =		2.74	No Calibration	-
	R_S =		4.43	No Calibration	-
	T_P =		2.27	2.50	2.83
	T_S =		4.85	5.52	4.75

Note: These stations did not record the HE calibration shot, DIAMOND DUST or DIAMOND MINE. (Signal levels too low.)

*Peak-to-peak amplitude in microns at 1 Hz (no seismometer response correction).

V = Vertical, R = Radial, T = Transverse, P = 1st Compressional wave arrival, S = Shear wave.

2.3. MAGNITUDE CALCULATIONS

The magnitude determination of an earthquake or a shot is a subject of some confusion even among seismologists. Richter originally devised a local magnitude scale (M_L) to classify earthquakes by size in Southern California. This scale was established for a certain type seismometer, the Wood-Anderson torsional seismometer which detects horizontal ground motion. This instrument had a natural period of 0.8 seconds, damping 0.8, and a magnification of 2800. The magnitude equation used by Richter is given by

$$M_L = \log_{10} A - \log_{10} A_0 \qquad \text{(Richter)}$$

For a magnitude $M_L = 0$

$$A_0 = 1/1000 \text{ mm at a distance of 100 km.}$$

Hence an earthquake of $M_L = 3$ would have a trace deflection of one millimeter at a distance of 100 km. This system worked well for earthquakes recorded out to distances of about 600 km. The Wood-Anderson seismograph is not a very sensitive instrument and hence is not widely used. There are no Wood-Anderson seismographs used in the Nevada seismic net discussed in the previous section.

Richter then devised a surface wave magnitude scale (M_S) to classify larger shallow focus earthquakes recorded at teleseismic distances. This scale is based on the maximum amplitude of the surface wave having a period of 20 seconds. The magnitude equation for M_S is as follows:

$$M_S = \log A_{20} + 1.66 \log \Delta + 1.52 \qquad \text{(Richter)}$$

where Δ = distance in degrees
A = amplitude in microns

There are several other versions of this scale.

$$M_S = \log A_{20} + 1.66 \log \Delta + 2.0 \qquad \text{(SIPRI)}$$

$$M_S = \log A/T + 1.66 \log \Delta + 3.3 \qquad \text{(used in USSR--T not held to 20 seconds)}$$

$$M_S^B = 0.8 (\log A_{20} + 1.66 \Delta + 2.0) + 1.4 \qquad \text{(M. Båth)}$$

For small yield shots long period surface waves are not generated so the surface wave magnitude scale is not applicable to our studies.

Richter devised a body wave magnitude (m_b) scale to be used for earthquakes at distances beyond 200 km (especially deep focus earthquakes that do not generate much surface wave energy). The general equation used by Richter is of the form

$$m_b = \log A/T + Q$$

where Q is a constant that is a function of distance.

The magnitude scales are relate y the following equations:

$$m_b = 0.63\ M_S + 2.5 \qquad \text{(Richter)}$$

$$m_b = 0.56\ M_S + 2.9 \qquad \text{(IUGG-IASPEI Committee on magnitudes at Zurich, 1967)}$$

$$m_b = 1.7 + 0.8\ M_L - 0.01\ M_L^{\ 2} \qquad \text{(Richter, and Wilmore, ISC)}$$

The body wave magnitude scale (m_b) has been used to determine the equivalent magnitude of most nuclear shots although recently there has been some effort to use the surface wave magnitudes especially for the larger yield devices. Considerable scatter is often encountered in body wave magnitude calculations for any given shot. Evernden (1967) has studied these variations and has shown that a large part of the scatter can be traced to geological variations in the earth's crust and upper mantle. He has devised body wave magnitude scales for the Eastern United States and the Western United States that are based on the branch of the travel time curve for which the first arrival is recorded at any particular station. Hence, his Western United States body wave magnitude curve, where the first arrival is a refracted wave (head wave) traveling with a velocity of 7.9 km/sec., is given as

$$m_{7.9} = -7.55 + 1.21\ (\log A/T + 3.04 \log \Delta).$$

This formula is applicable over a range of approximately 200 to 1,050 km where the wave refracted along this interface is the first arrival. This refractor is at a depth of about 26 km. Hence at ranges shorter than 200 km it can not be used. A similar type equation is used for waves arriving as first arrivals which travel along a deeper interface (156 km in the Western U.S.) with a velocity of 8.5 km/sec. This equation is valid for distance ranges of approximately 1000 to 1700 km.

The original m_b and Evernden's $m_{7.9}$ and $m_{8.5}$ magnitude scales were not designed to be used at the distances for which data are available for DIAMOND DUST/DIAMOND MINE. One approach to the problem is to use Evernden's equation for compressional waves traveling with the P_g velocity (6.0 km/sec). This technique is currently being investigated and will be reported on in later reports. A second approach is to employ a technique that the USGS/NCER developed to determine magnitudes of small earthquakes recorded at relatively short distances (Healy, 1971 and Eaton, 1970) in the Western United States. This technique is based on the length of the seismic wave train coda and the equation for the NTS area is given as

$$M_D = -1.03 + 1.82 \log F + 0.0025\, \Delta + \gamma$$

where F = length in seconds of the seismic coda where the signal level remains above 1 cm as measured on a Geotech Viewer.

The USGS have found that $M_D = M_L$ for small earthquakes below $M_D = 2.5$. However, a study (Fischer, 1971) of 1970 shots at NTS disclosed a significant variation in m_b values determined at teleseismic distances and m_b values determined using the relationship between M_L and m_b. Hence, M_D can not be used directly to determine an equivalent m_b. The latter determination is important since that is the magnitude scale used in decoupling estimates (SIPRI, 1968, Rodeau, 1971).

The M_D magnitude technique was used to compute magnitudes for the following (Fischer, 1971):

	M_D
DIAMOND DUST, May 12, 1970--3 stations	1.8
DIAMOND MINE, Jul 1, 1971--5 stations	2.2
HE of 2/4/71 (1000 lbs.)----3 stations	1.4
HE of 4/29/71 (6½ tons)-----7 stations	2.5
HE of 5/28/71 (1000 lbs.)---4 stations	2.0
HE of 6/15/71 (1000 lbs.)---4 stations	1.7

Conversion of the above to m_b magnitudes using the $M_L - m_b$ conversion equation yields m_b values that are too large. However, the relative values shown above are believed to be significant insofar as relating the above events to each other. The low magnitude of the 2/4/71 HE shot compared to the other HE shots would lend support to the theory that this shot did not go at full yield.

The .4 magnitude unit between DIAMOND DUST and DIAMOND MINE would indicate a decoupling factor of about 2.5.

3 CONCLUSIONS AND RECOMMENDATIONS

1. The trace amplitudes of broadband seismograms showed that DIAMOND MINE was on the average a factor of 1.6 (with a maximum of 2.5) larger than DIAMOND DUST. The seismic station at Beatty showed DIAMOND MINE to be a factor of 2.6 larger.

2. The spectral ratios of DIAMOND MINE to DIAMOND DUST showed that at 2 Hz, DIAMOND MINE was on the average a factor of 3.2 to 5.6 larger than DIAMOND DUST. The spectral ratios at the lower frequencies are believed to be a more accurate indicator of the true effective decoupling. At 10 Hz this average factor ranged from 2.2 to 2.5.

3. On the basis of coda length magnitude (M_D) determinations, DIAMOND MINE was 0.4 of a magnitude unit larger than DIAMOND DUST which is the equivalent of a factor of 2.5.

4. On the basis of high explosive shot data from NTS and from other areas, the HE shot of February 4, 1971 did not appear to go at full yield.

5. If additional shots are planned for this series in Area 16, it is strongly recommended that the seismograph stations of the NTS, CNTS, and CGS nets be alerted and that gains be adjusted so that good recordings will be obtainable. As a minimum the following stations should be specifically included:

NTS Net - NT14, NT16
CGS Net - BTY, LSM, DAC, LEE, NEL, TPH

It would be very desirable to have the following additional stations also included:

NTS Net - NT11, NT13, NT18, NT21, NT22, NT23
CNTS Net - NRGF, NRWP
CGS Net - MCV, SMN, NYRS, NYMC, BMN, ELY

The data from these stations will allow a better statistical comparison between the tamped and decoupled shots and will allow an m_b determination (stations at $\Delta > 200$ km) for the tamped shot which can be compared with the local magnitude (M_D) calculations for all events of the MIGHTY MITE series which were recorded at smaller distances. These stations should also be recorded on magnetic tape, if possible.

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Willis, D. E. and R. F. Hand, Seismic Measurements of DIAMOND DUST (U), University of Michigan, Geophysics Laboratory, Final Report No. 8071-33-F_3/3620-2-T, POR-6438, January 1971. (CONFIDENTIAL)

Fischer, F. G., USGS/NCER, Personal communication, 1971.

Healy, J. H., USGS/NCER, Personal communication, 1971.

Tendall, D., Sandia Labs, Personal communication, 1971.

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SIPRI, Seismic Methods for Monitoring Underground Explosions, International Institute for Peace and Conflict Research, (SIPRE), Stockholm, 1968.

Evernden, J., "Magnitude Determination at Regional and Near Regional Distances in the United States," Bull. Seism. Soc. Am., Vol. 57, No. 4, August 1967.

Eaton, J. P., M. E. O'Neil, and J. N. Murdock, "Aftershocks of the 1966 Parkfield-Cholame, California Earthquake: A Detailed Study," Bull. Seis. Soc. Am., Vol. 60, No. 4., pp. 1151-1197, August 1970.

Rodean, H. C., "Nuclear-Explosion Seismology," AEC Critical Review Series, p. 1561, 1971.

APPENDIX A
DIAMOND MINE SEISMOGRAMS

The following seismograms are the signals received at the five stations. On the North Site we have marked the phases analyzed. The P_1 phase is the first arrival on the vertical component; the P_{max} phase is that phase which has the maximum energy on the broadband vertical and which arrives before the first S motion; the S_{max} phase is that phase which has the maximum S energy on the longitudinal, or north component. These signatures are filtered and the data obtained are the particle velocities corresponding to these phases.

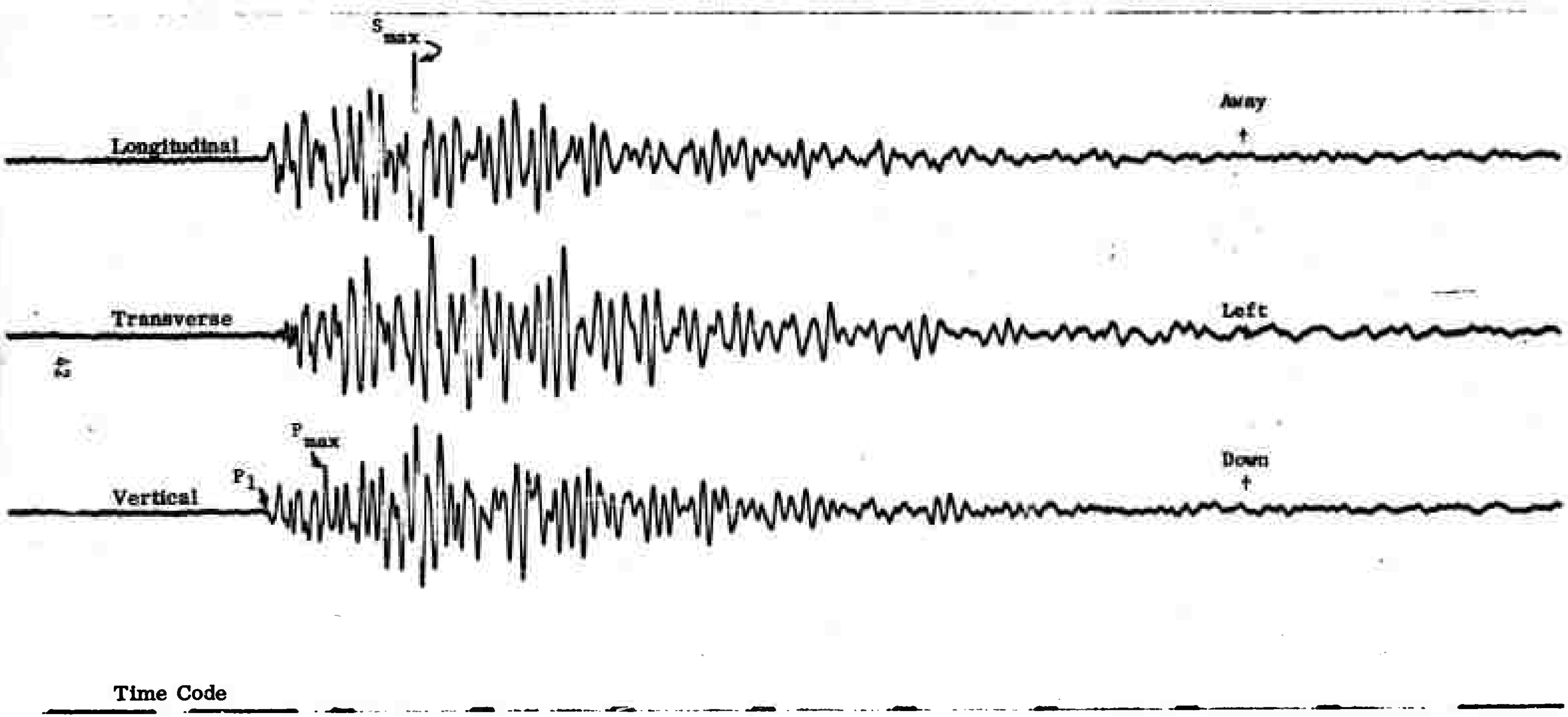


Figure A-1. Three-Component Seismogram of DIAMOND MINE recorded at 2.5 km North, Total gain 12 db.

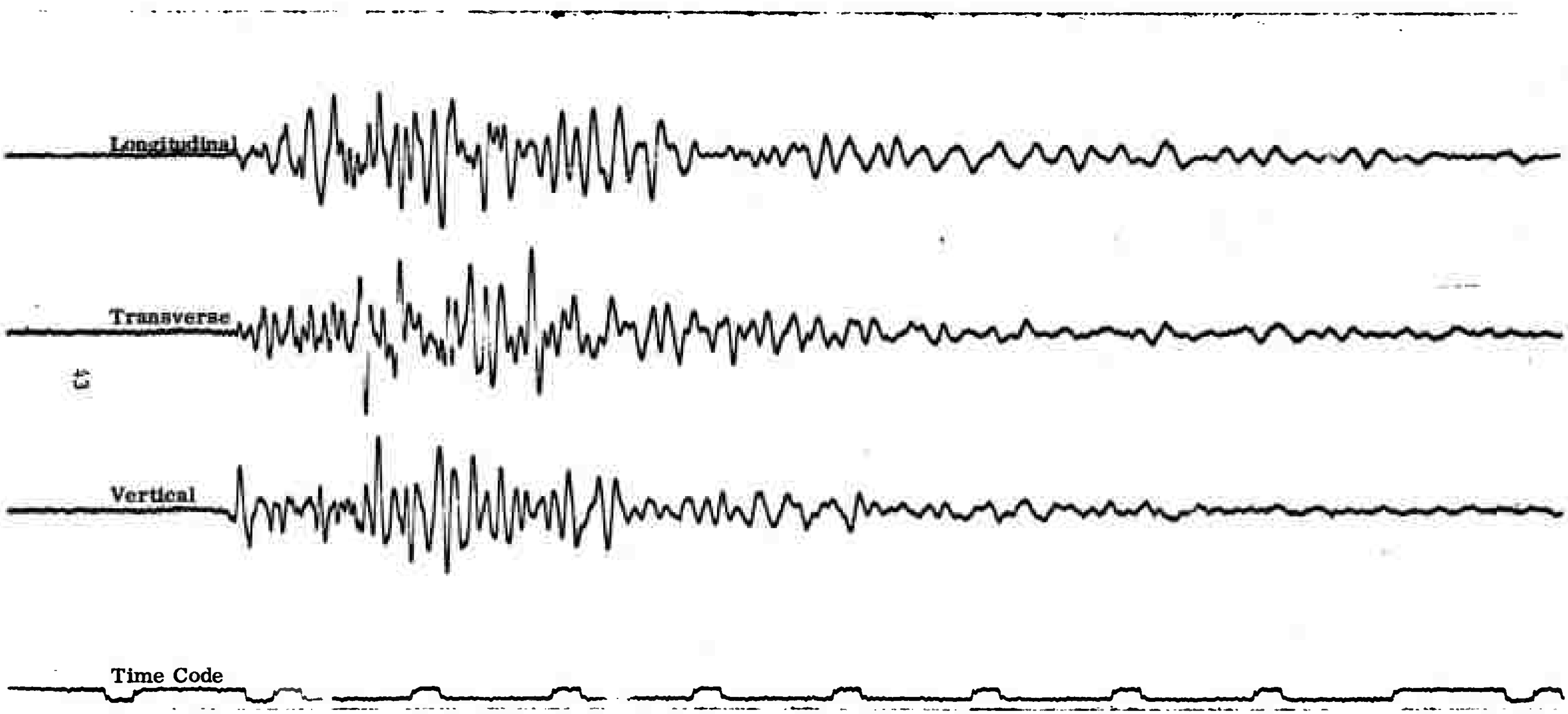


Figure A-2. Three-Component Seismogram of DIAMOND MINE recorded at 2.5 km East (Pole Line Rd.), Total gain 6 db.

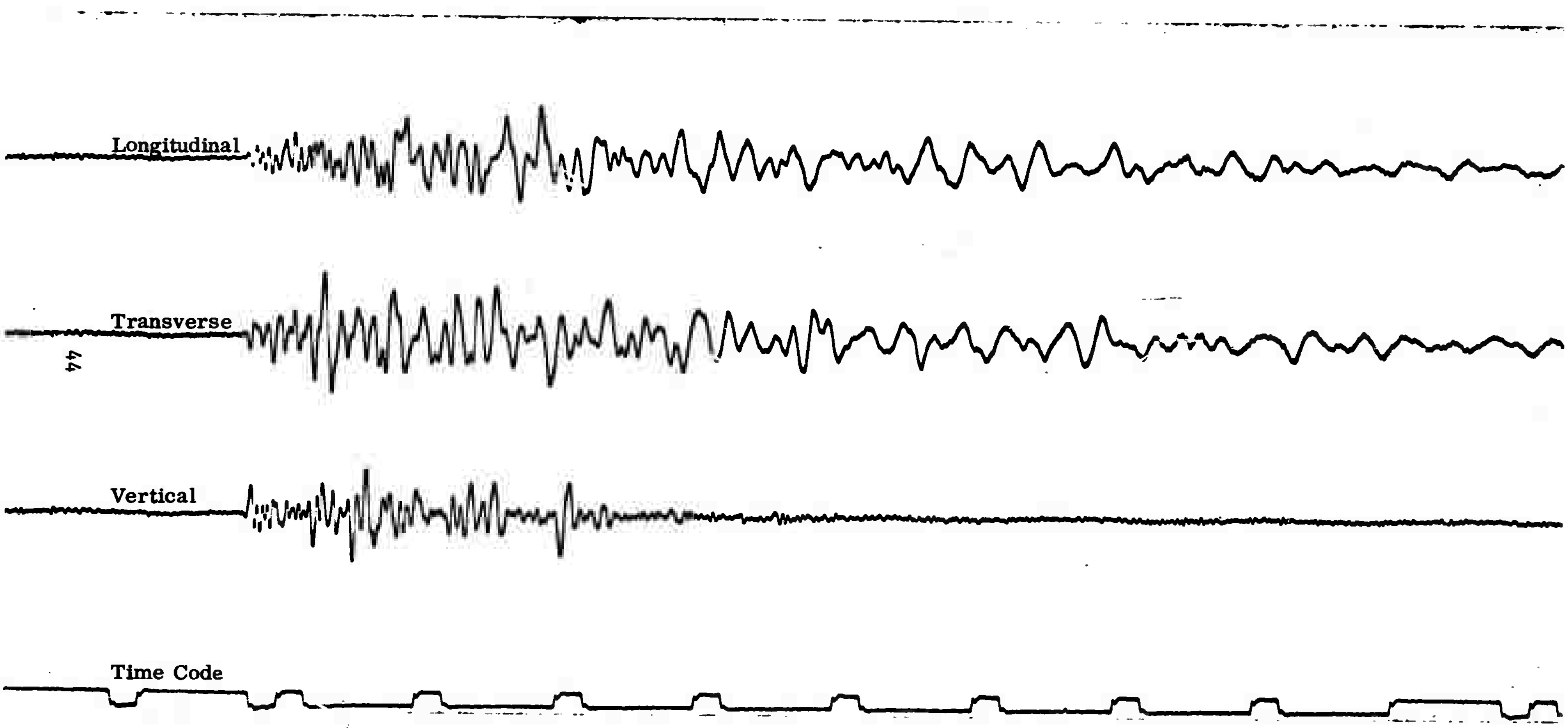


Figure A-3. Three-Component Seismogram of DIAMOND MINE recorded at 2.5 km Southeast, Total gain 12 db.

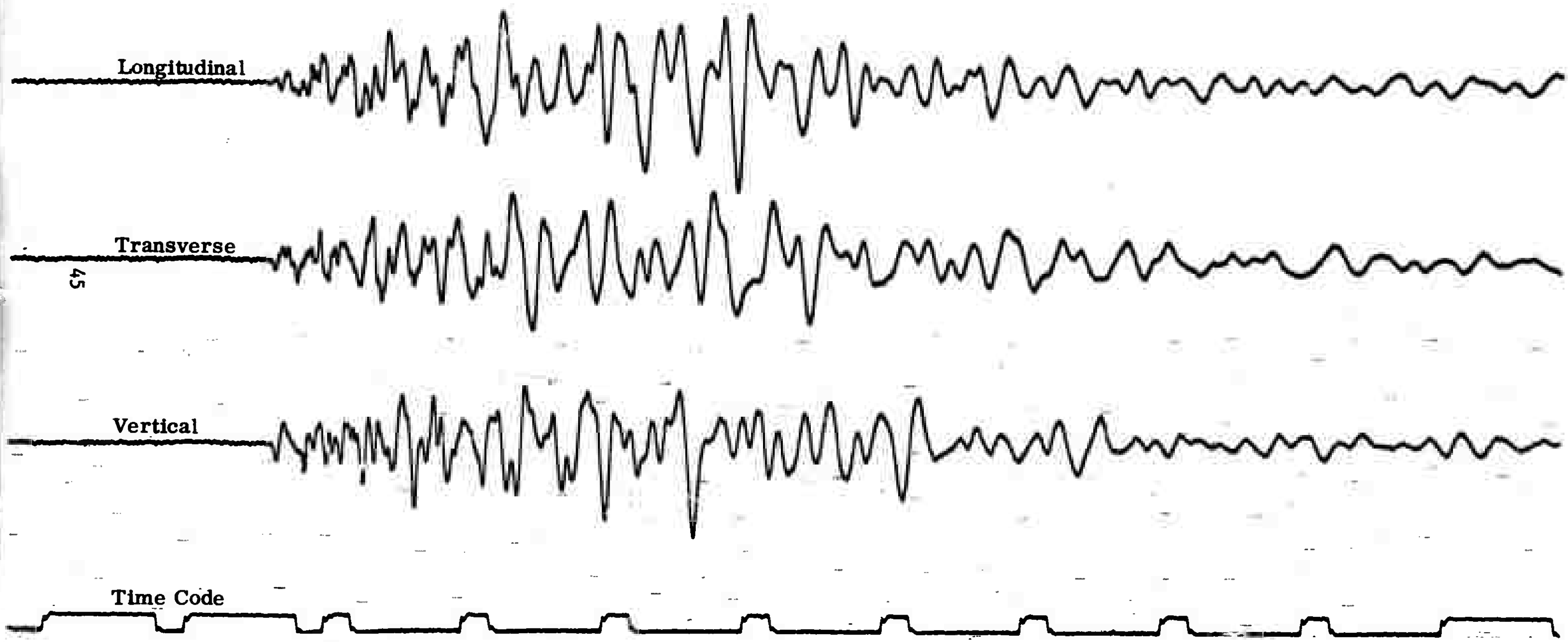


Figure A-4. Three-Component Seismogram of DIAMOND MINE recorded at 2.5 km South, Total gain 12 db.

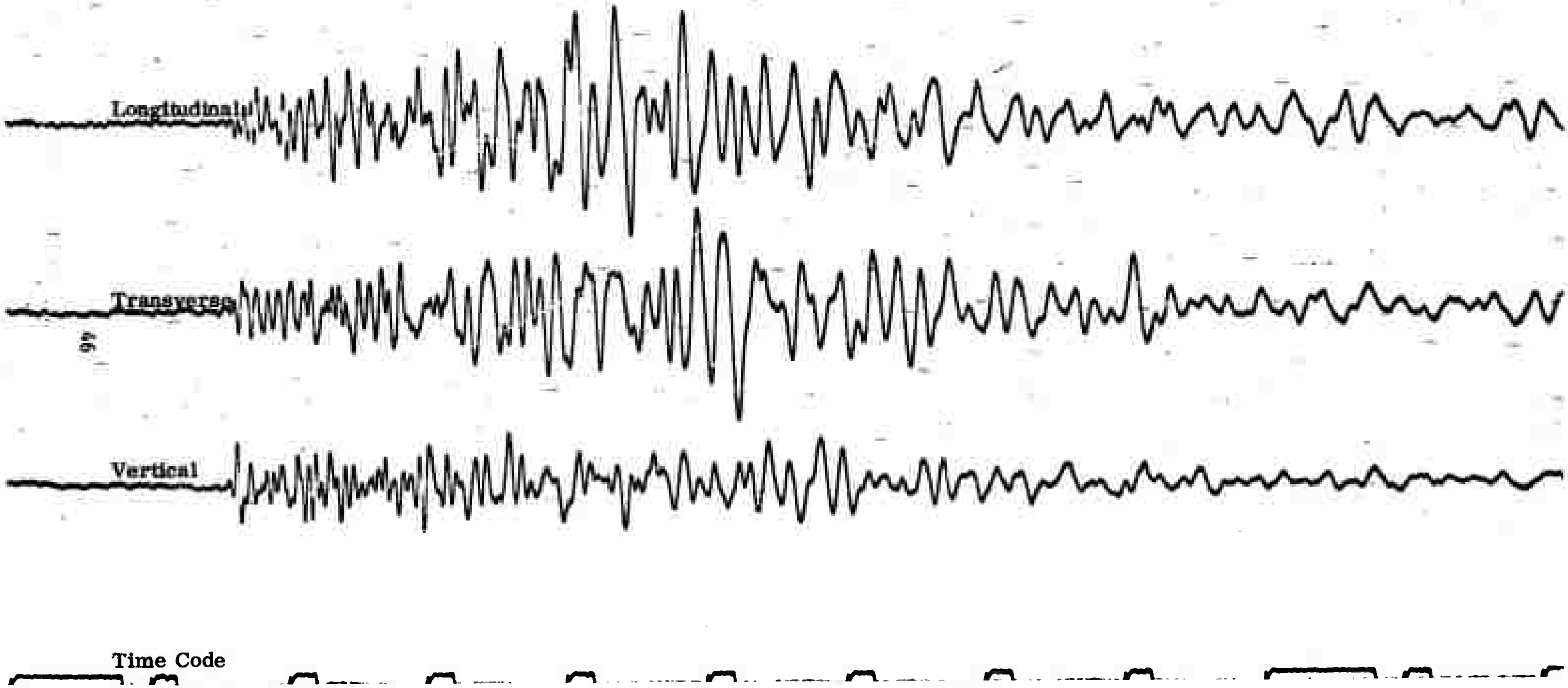


Figure A-5. Three-Component Seismogram of DIAMOND MINE recorded at 6.0 km North (Pahute Mesa Site), Total gain 18 db.

APPENDIX B
HIGH EXPLOSIVE SHOT SEISMOGRAMS

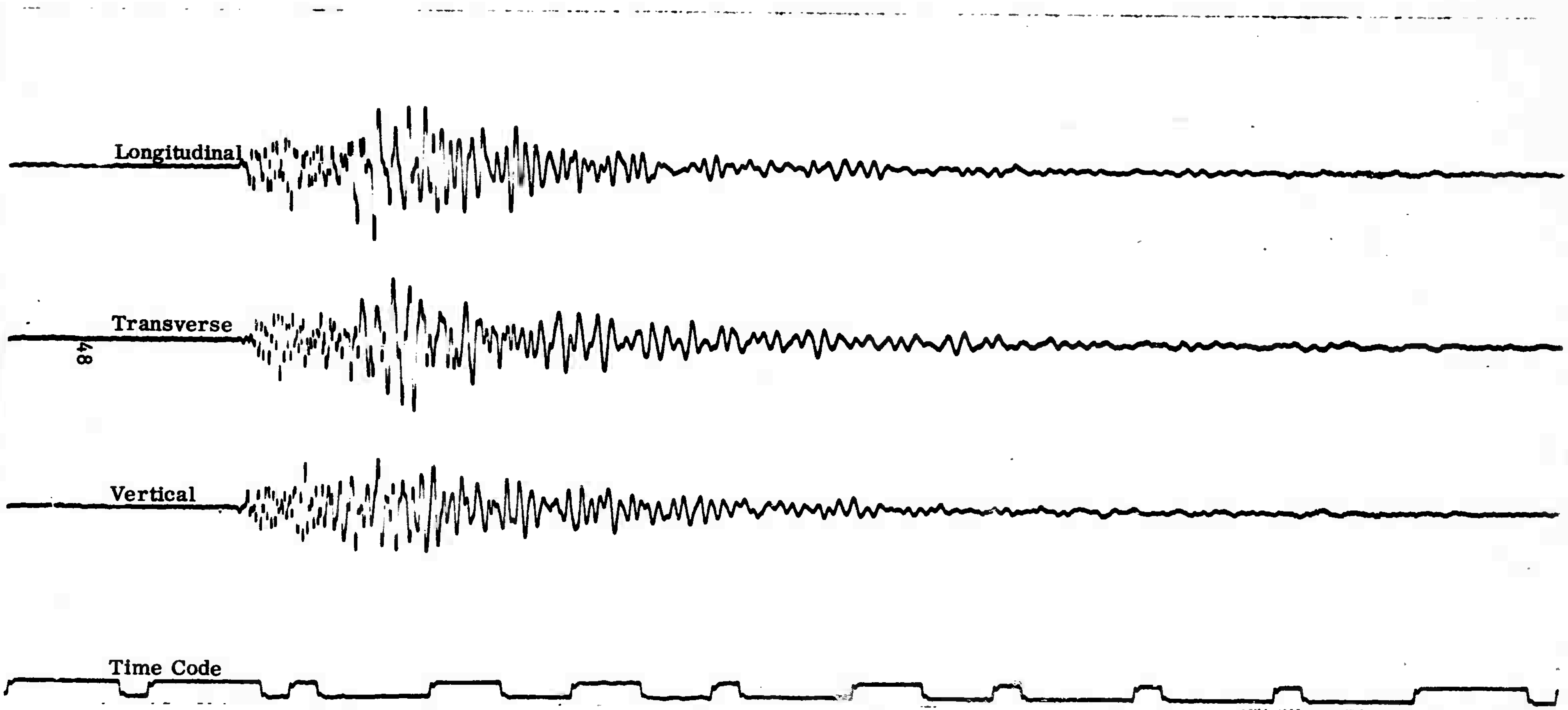


Figure B-1. Three-Component Seismogram of High Explosive Event (DIAMOND MINE series) recorded at 2.5 km North, Total gain 24 db.

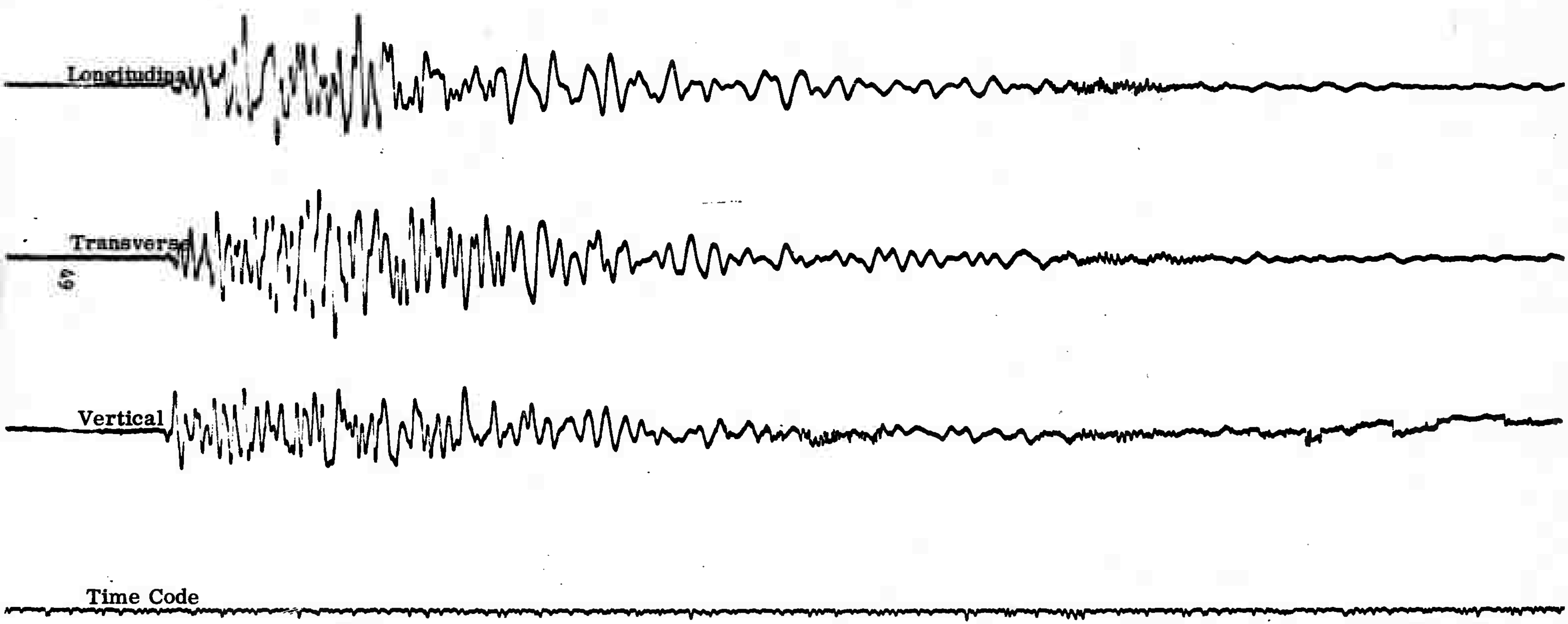


Figure B-2. Three-Component Seismogram of High Explosive Event (DIAMOND MINE series) recorded at 2.5 km East, Total gain 18 db.

Figure B-3. Three-Component Seismogram of High Explosive Event (DIAMOND MINE series) recorded at 2.5 km Southeast, Total gain 18 db.

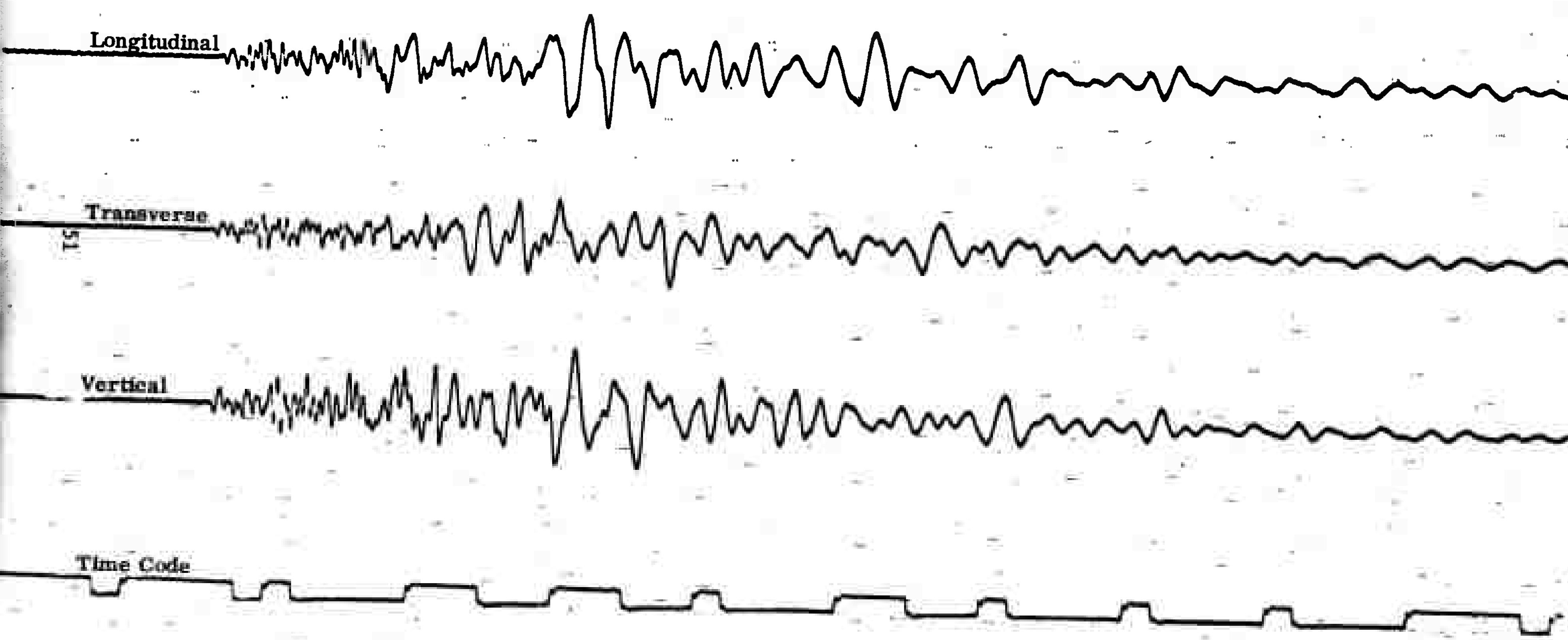


Figure B-4. Three-Component Seismogram of High Explosive Event (DIAMOND MINE series) recorded at 2.5 km South, Total gain 24 db.

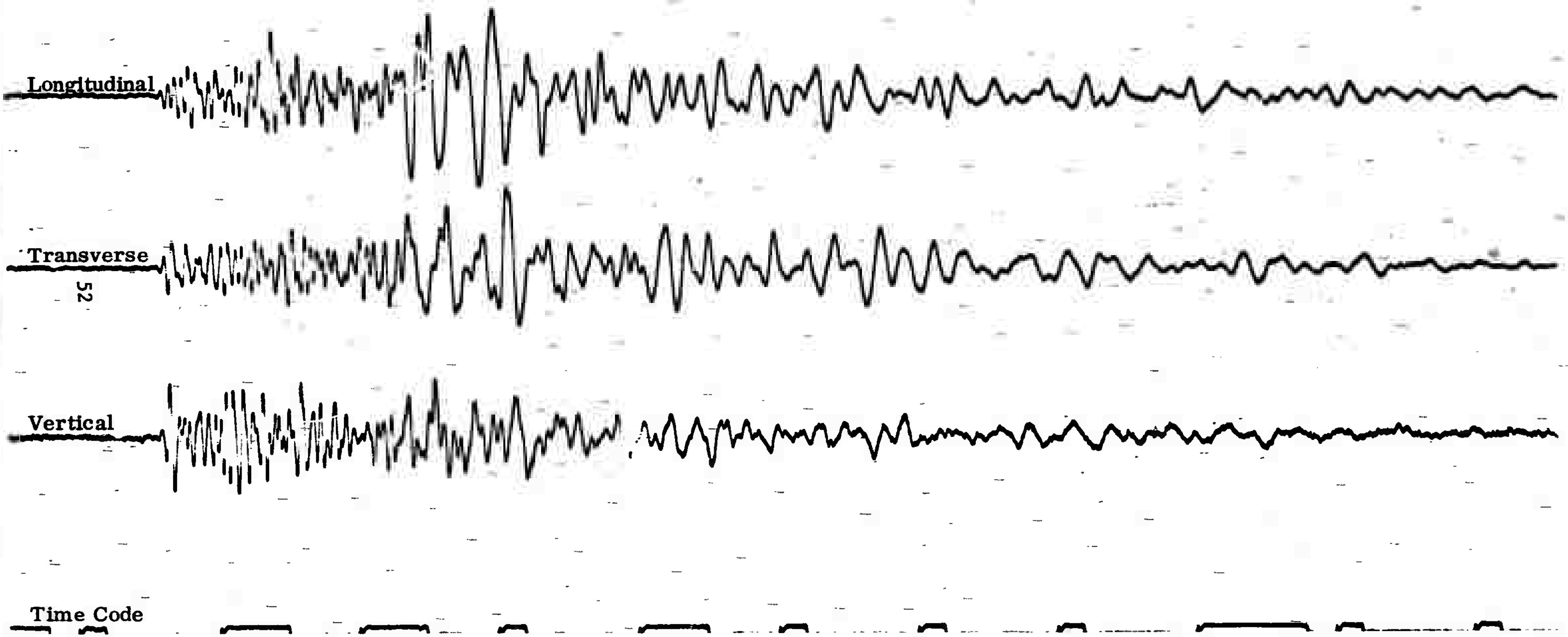


Figure B-5. Three-Component Seismogram of High Explosive Event (DIAMOND MINE series) recorded at 6.0 km North (Pahute Mesa Site). Total gain 30 db.

APPENDIX C
DIAMOND MINE SPECTRAL ANALYSES

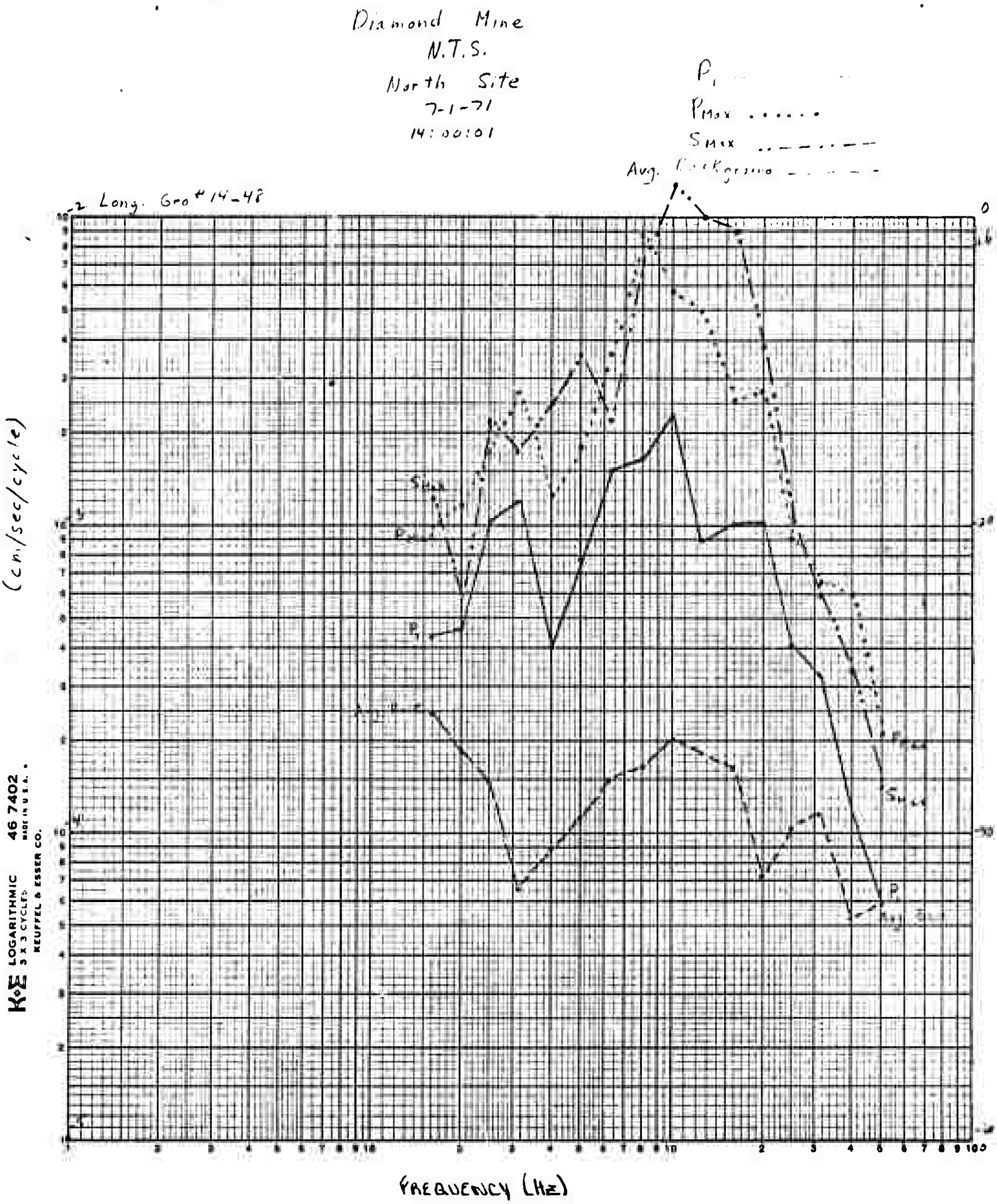
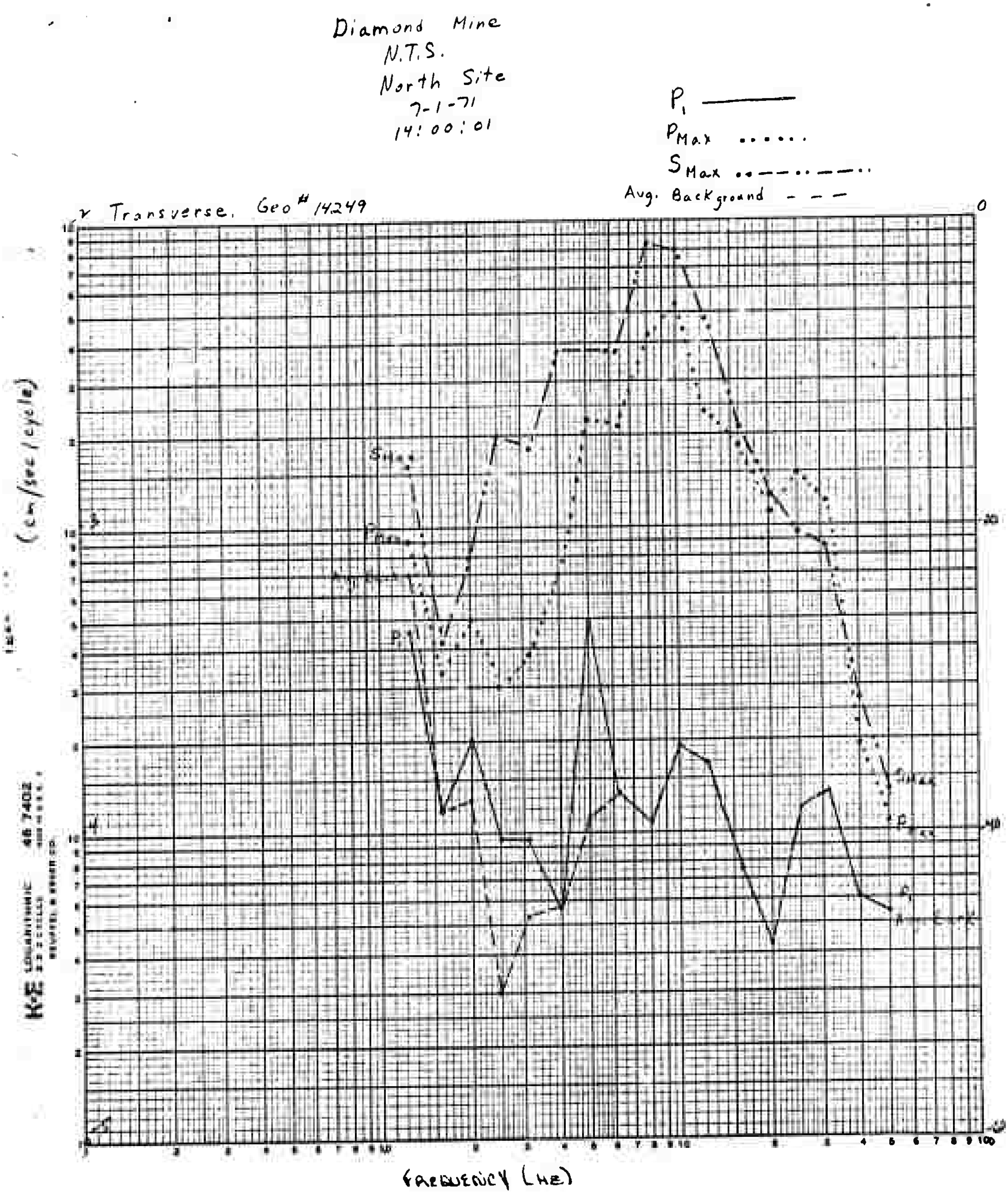


Figure C-1. DIAMOND MINE, NTS, North Site (Longitudinal)



C-2. DIAMOND MINE, NTS, North Site (Transverse)

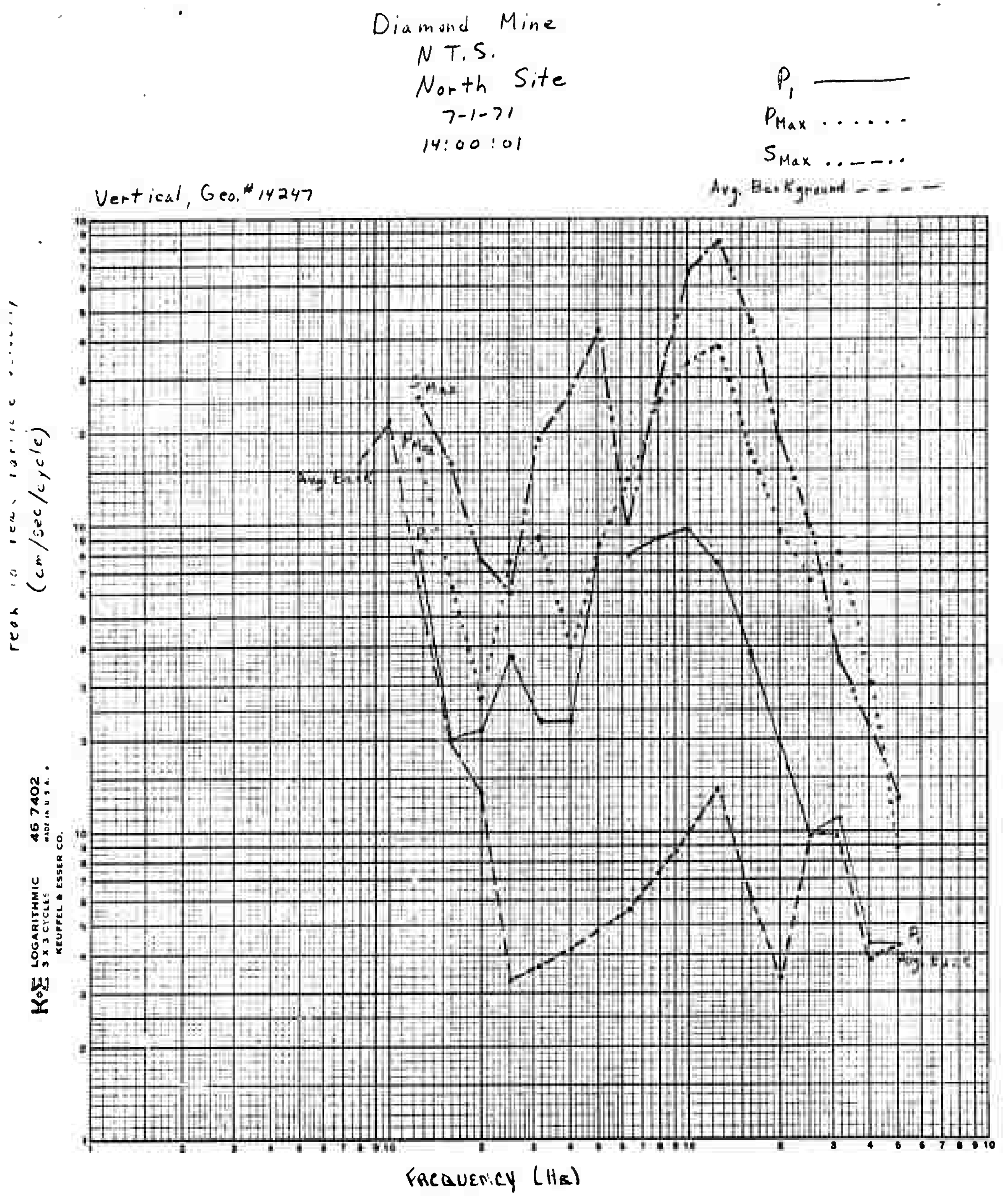


Figure C-3. DIAMOND MINE, NTS, NORTH SITE (Vertical)

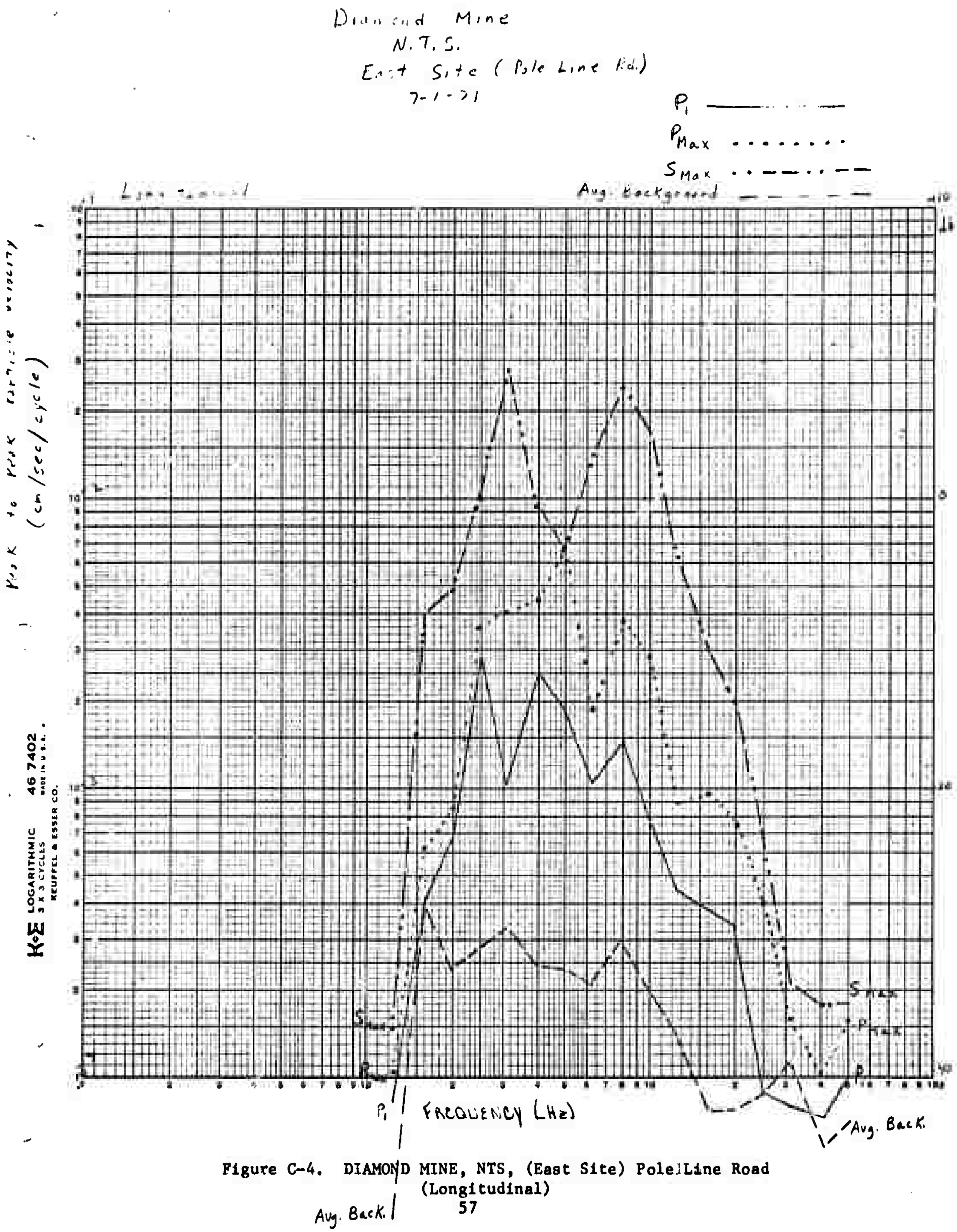


Figure C-4. DIAMOND MINE, NTS, (East Site) Pole Line Road (Longitudinal)

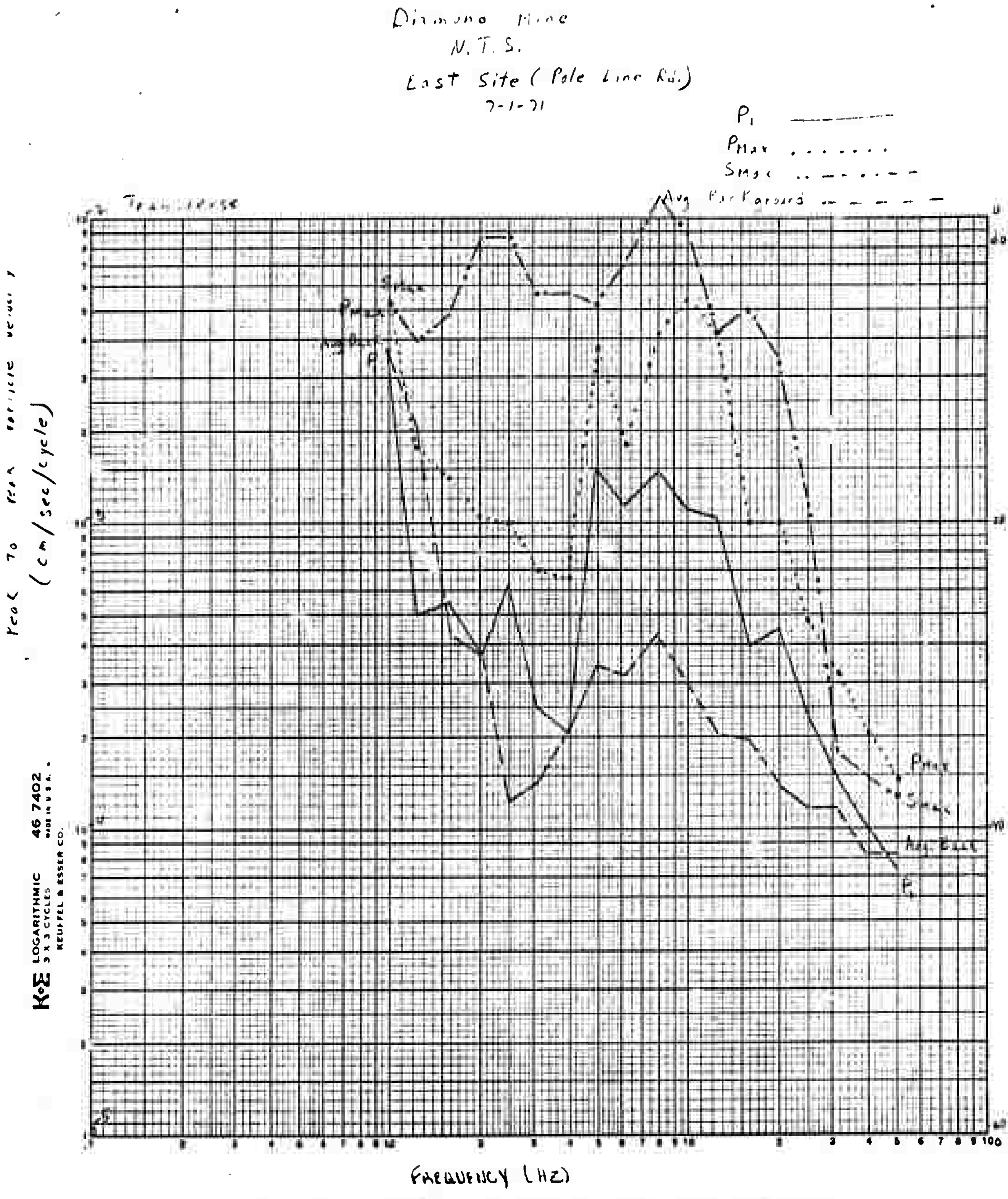


Figure C-5. DIAMOND MINE, NTS, East Site (Pole Line Road) (Transverse)

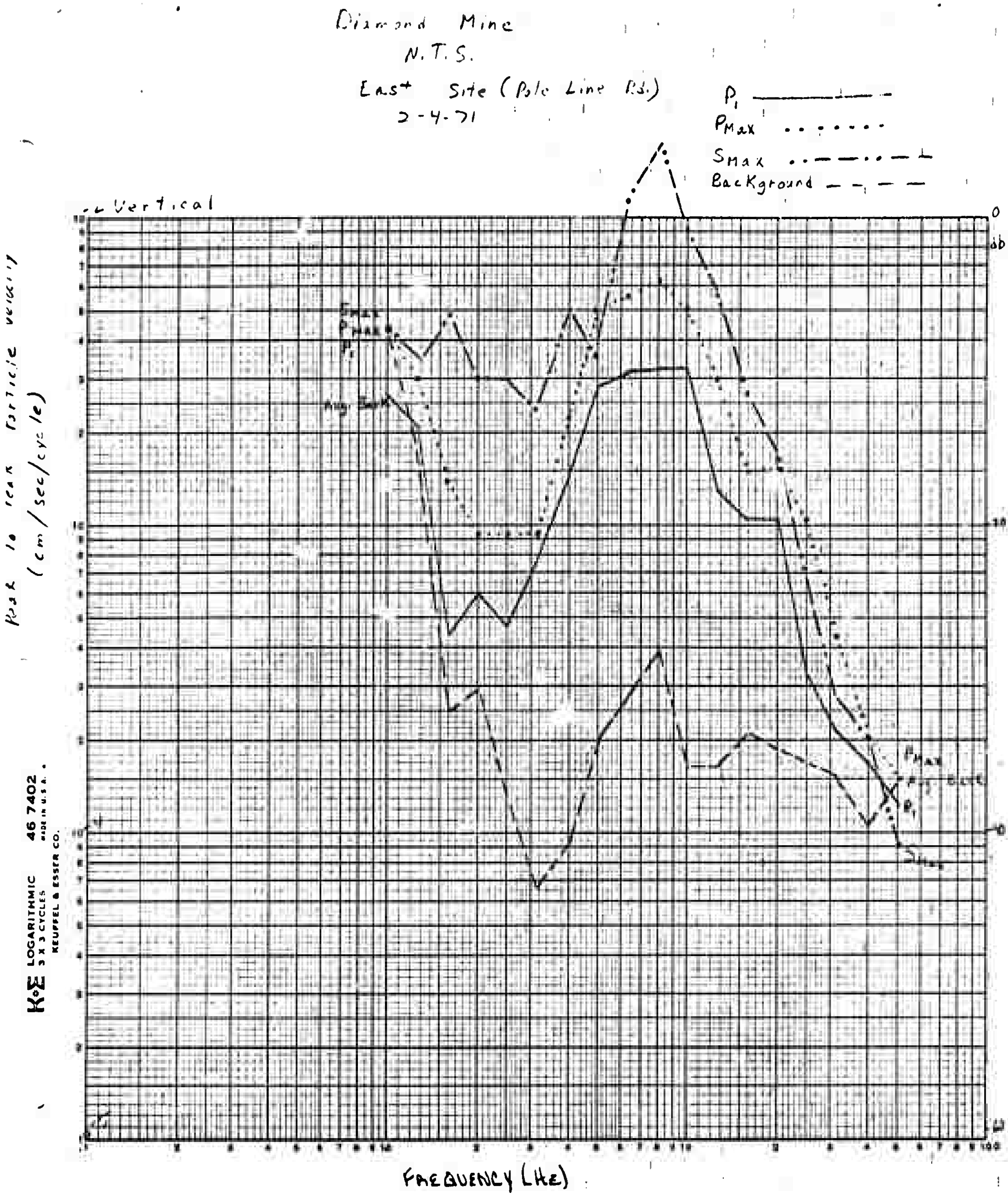


Figure C-6. DIAMOND MINE, NTS, East Site (Pole Line Road) (Vertical)

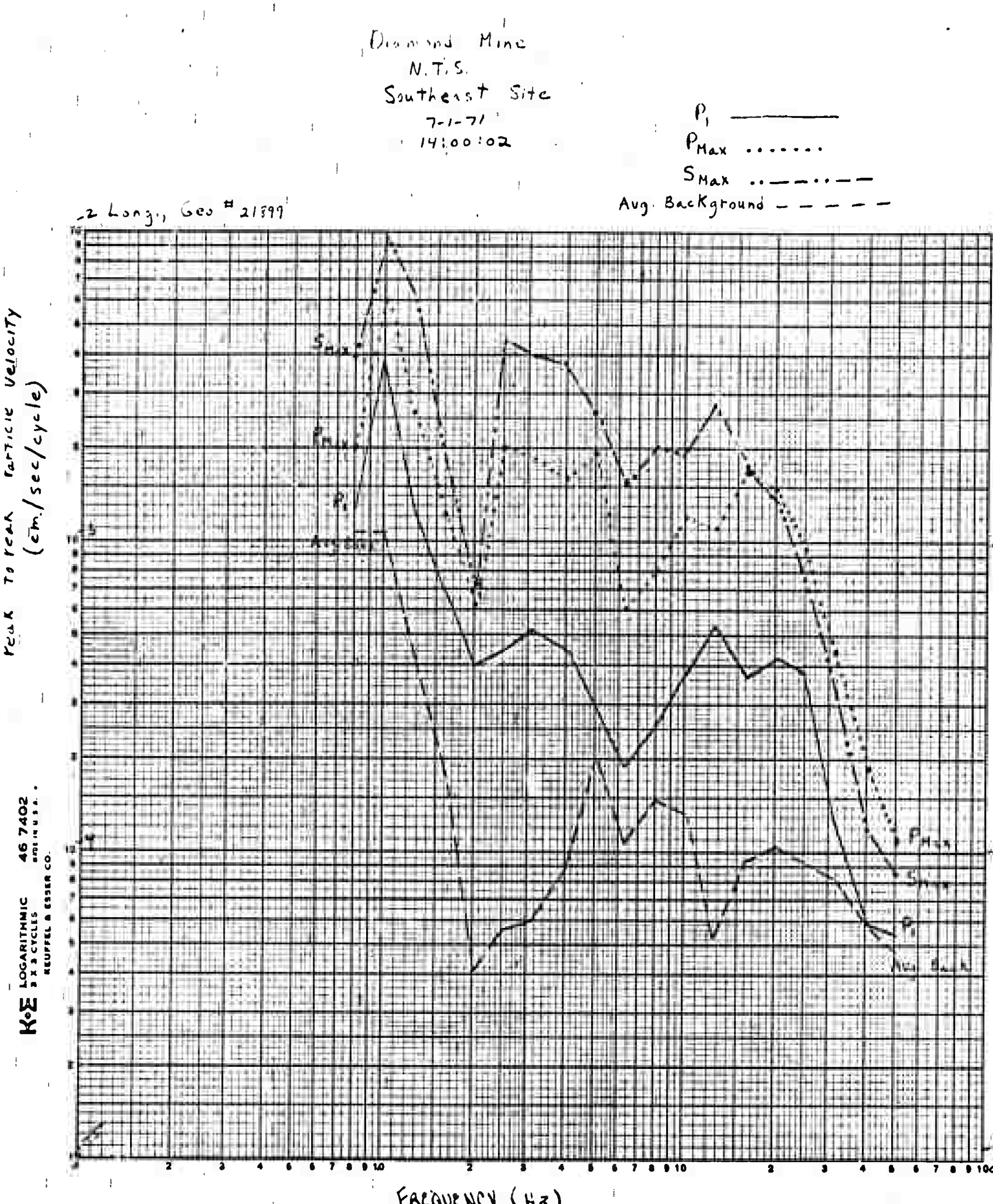


Figure C-7. DIAMOND MINE, NTS, Southeast Site, Longitudinal.

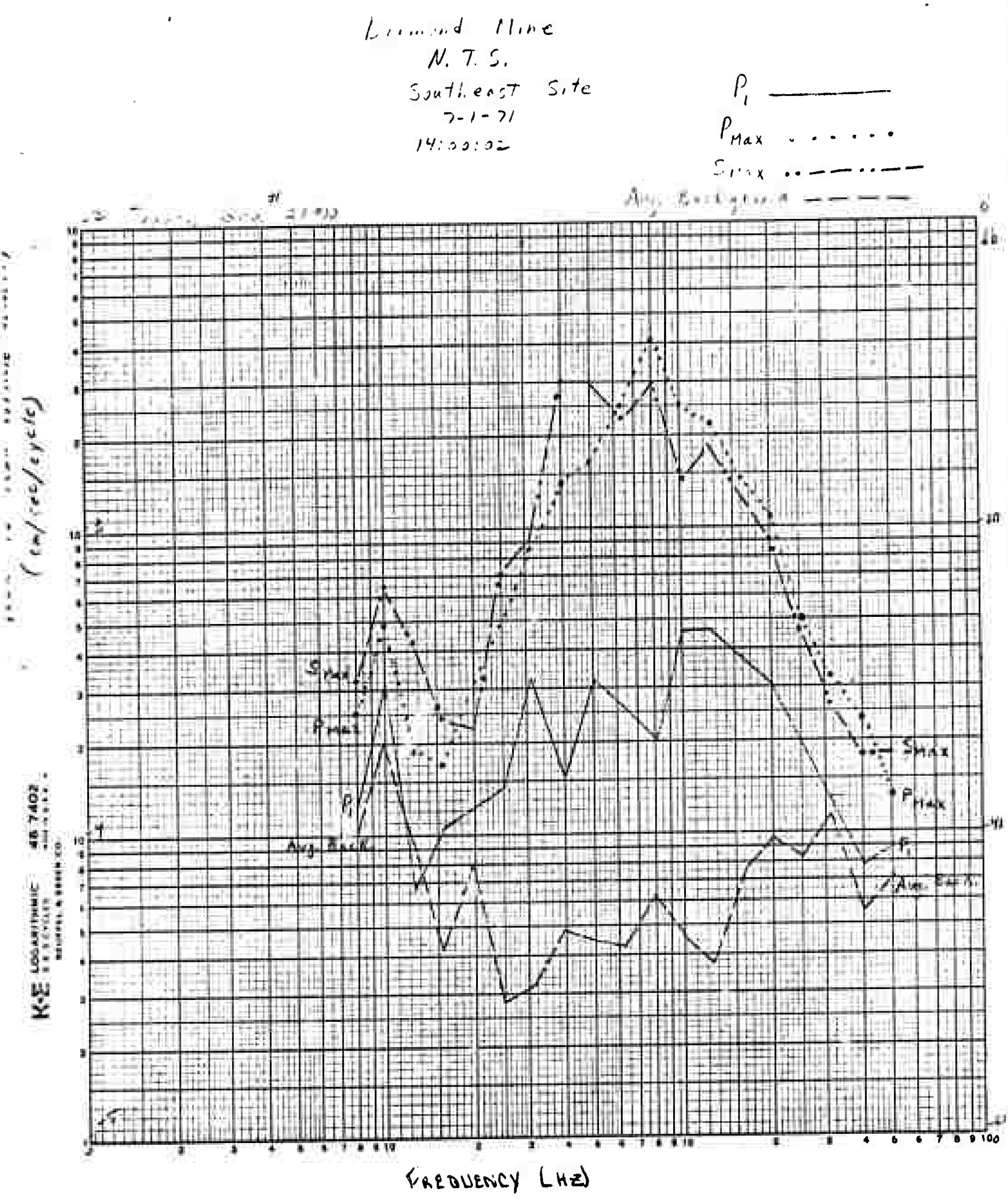


Figure C-8. DIAMOND MINE, NTS, Southeast Site, Transverse

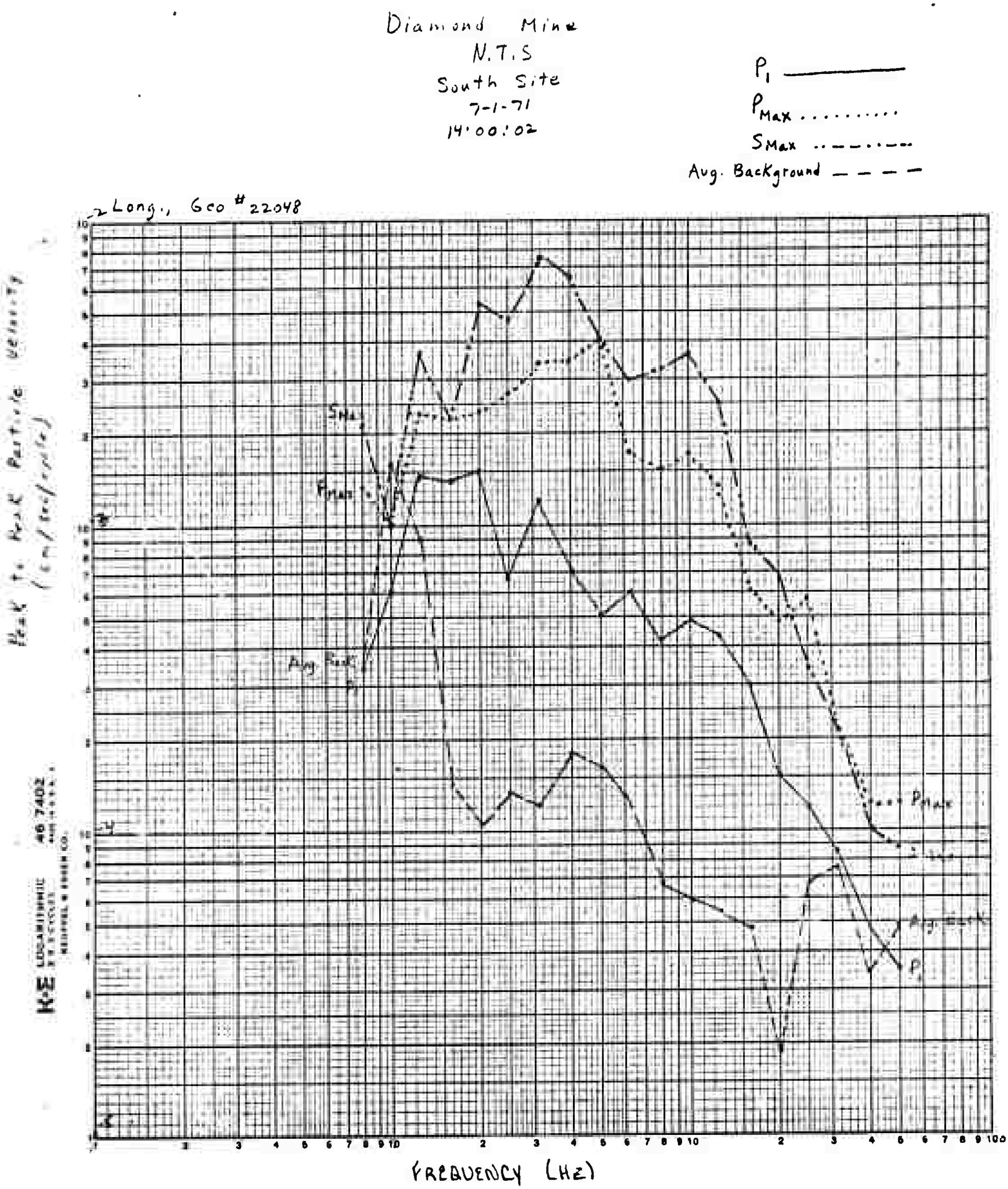


Figure C-9. DIAMOND MINE, NTS, South Site, Longitudinal

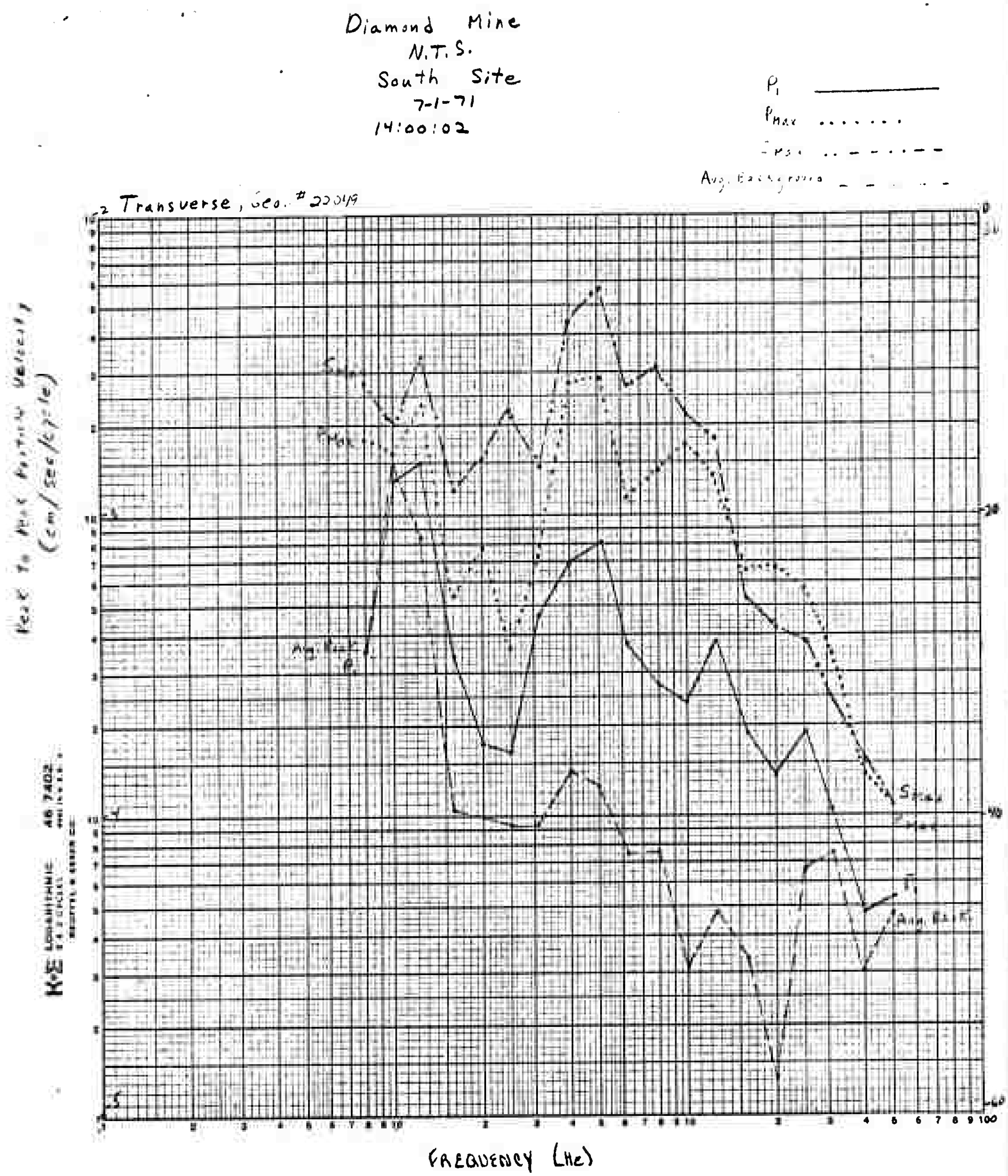


Figure C-10. DIAMOND MINE, NTS, South Site, Transverse

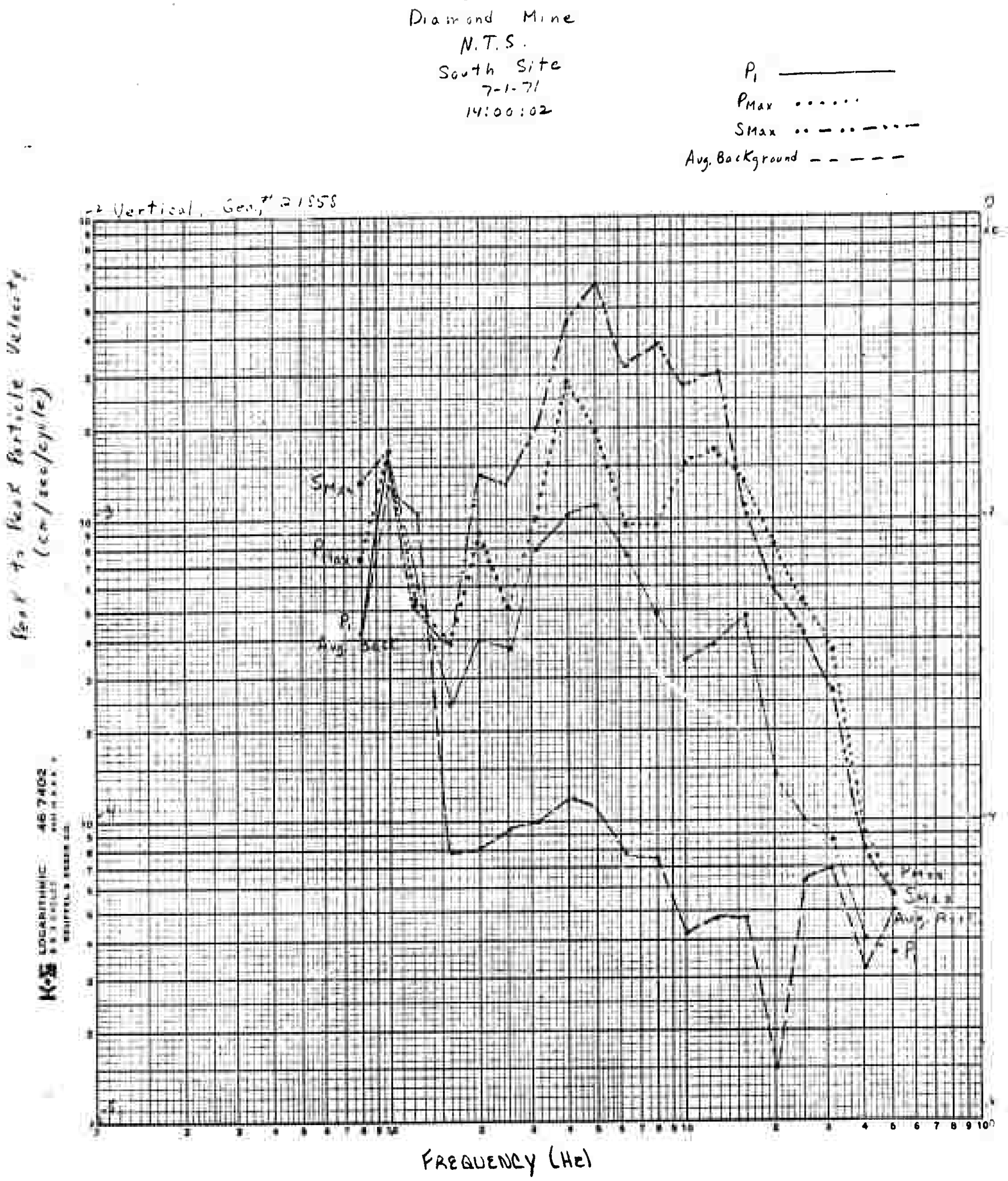


Figure C-11. DIAMOND MINE, NTS, South Site, Vertical

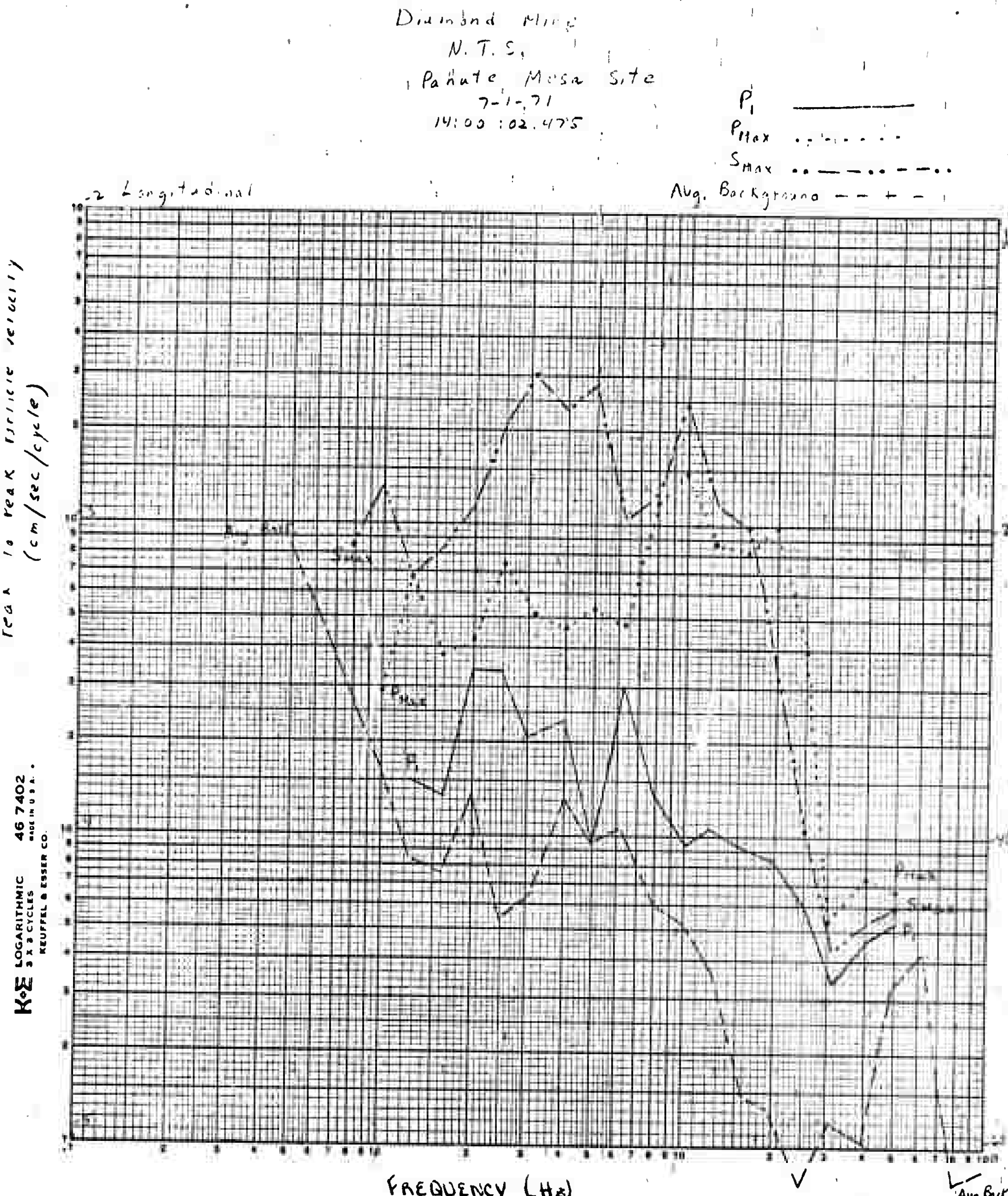


Figure C-12. DIAMOND MINE, NTS, Pahute Mesa Site (Longitudinal)

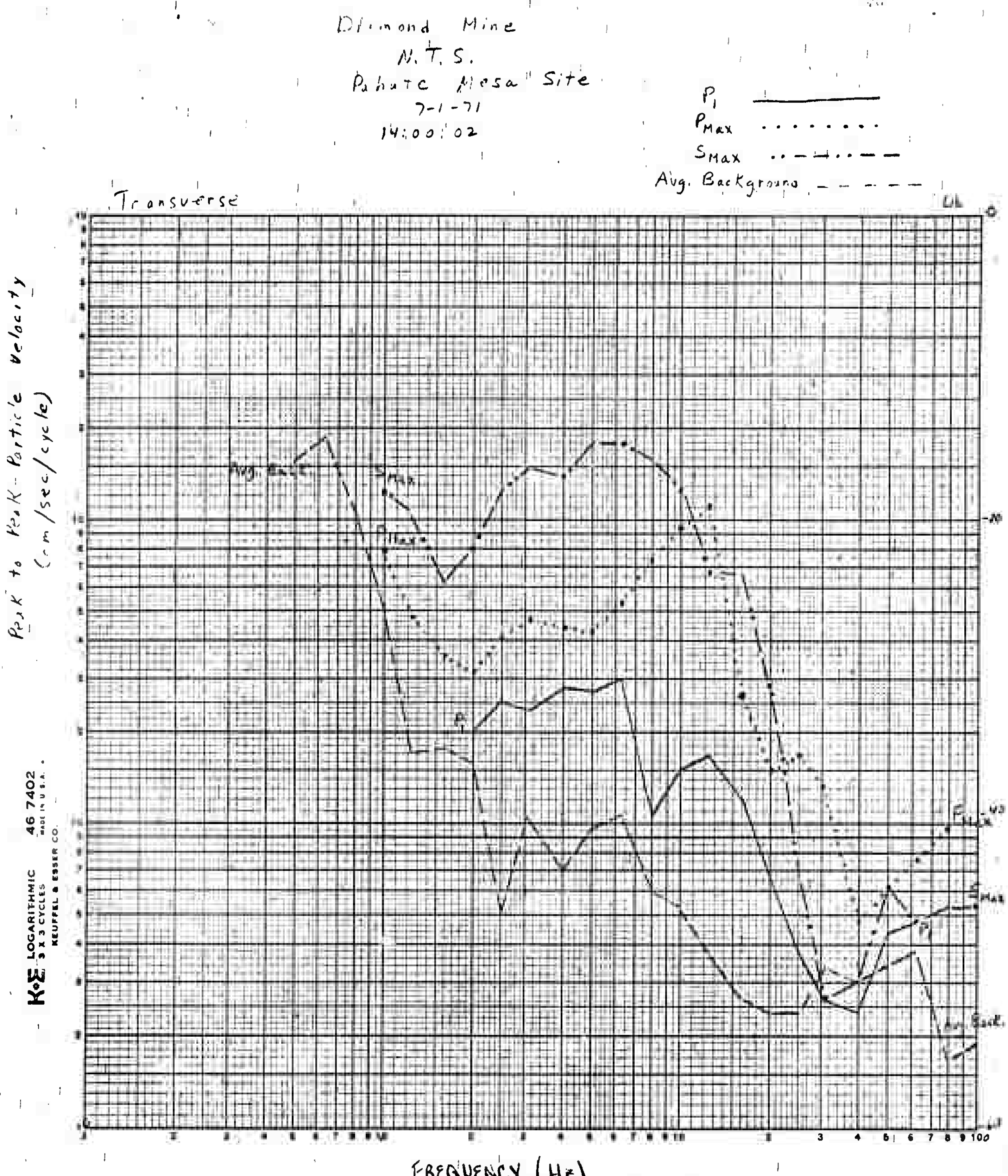


Figure C-13. DIAMOND MINE, NTS, Pahute Mesa Site (Transverse)

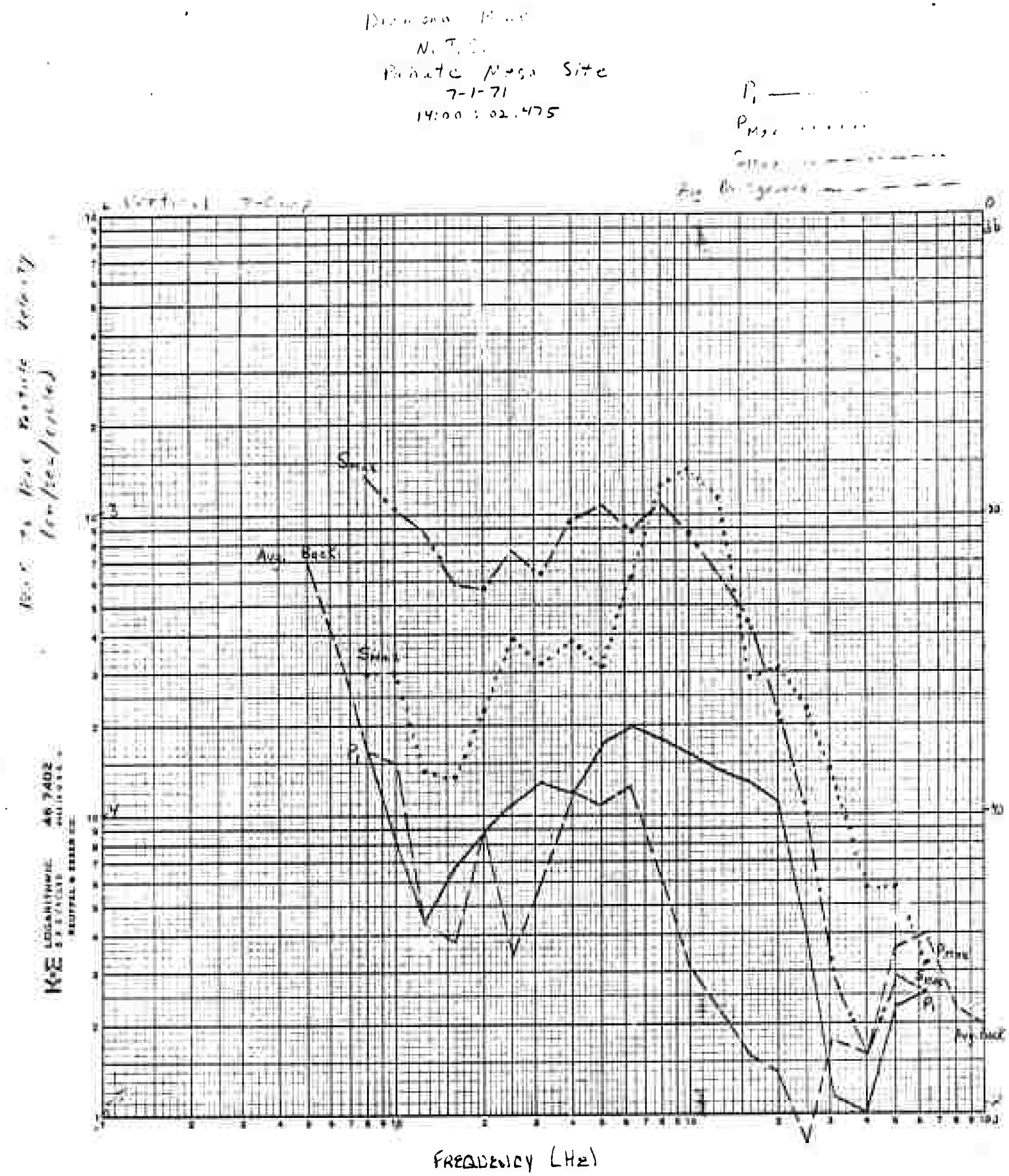


Figure C-14. DIAMOND MINE, NTS, Pahute Mesa Site (Vertical)

APPENDIX D
HIGH EXPLOSIVE SHOT SPECTRAL ANALYSES

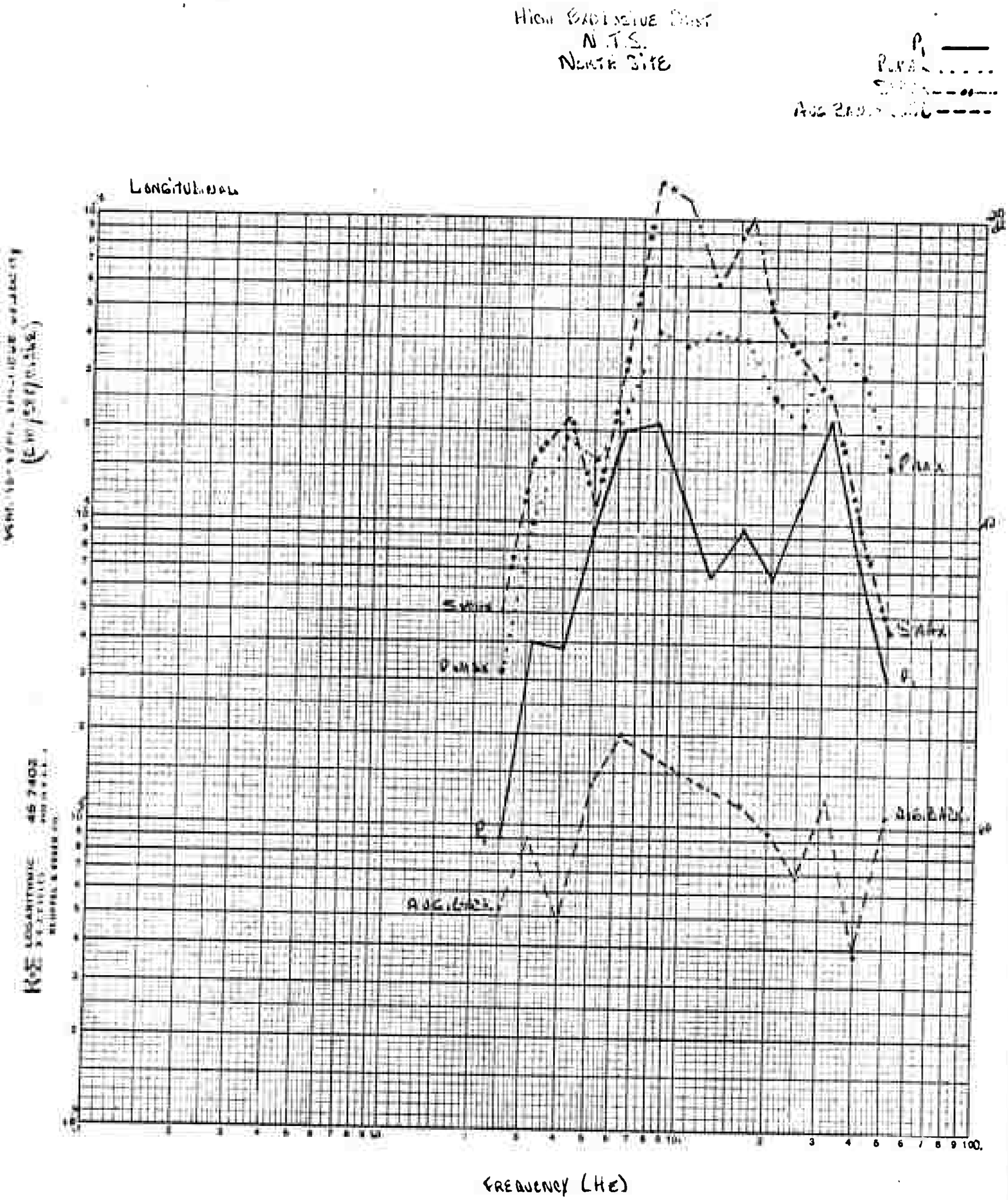


Figure D-1. High Explosive Shot, NTS, North Site, Longitudinal

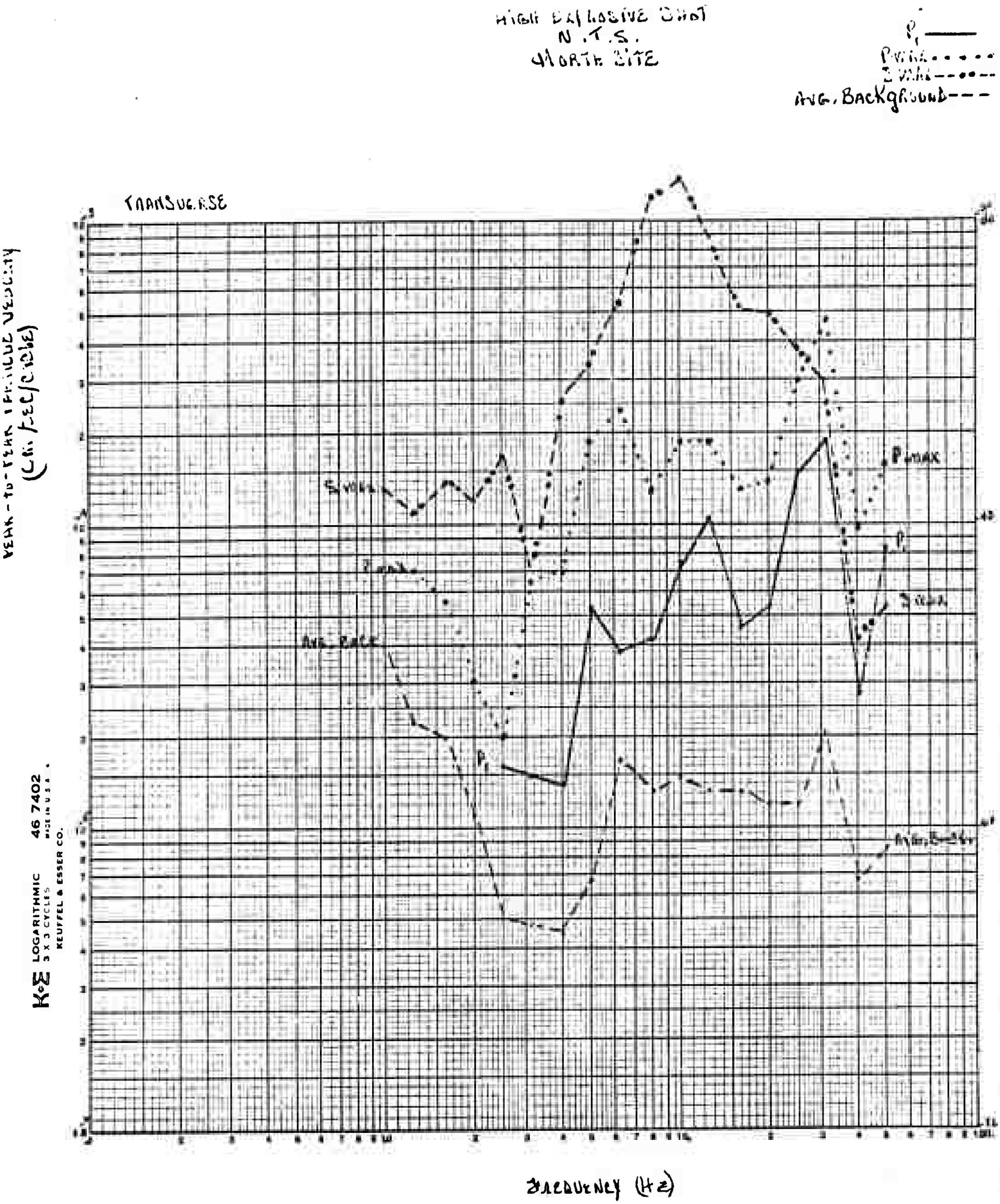


Figure D-2. High Explosive Shot, NTS, North Site (Transverse)

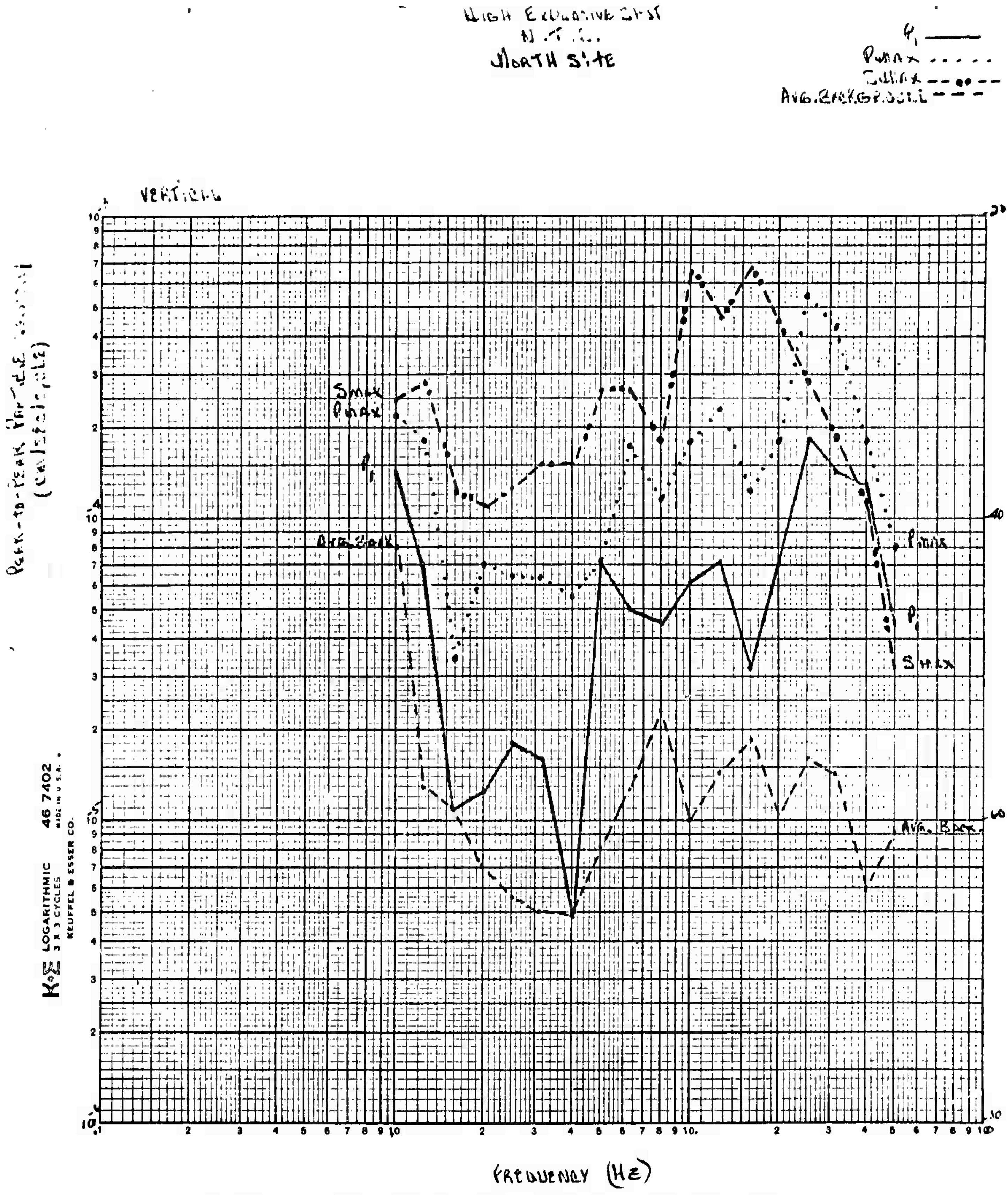


Figure D-3. High Explosive Shot, NTS, North Site (Vertical)

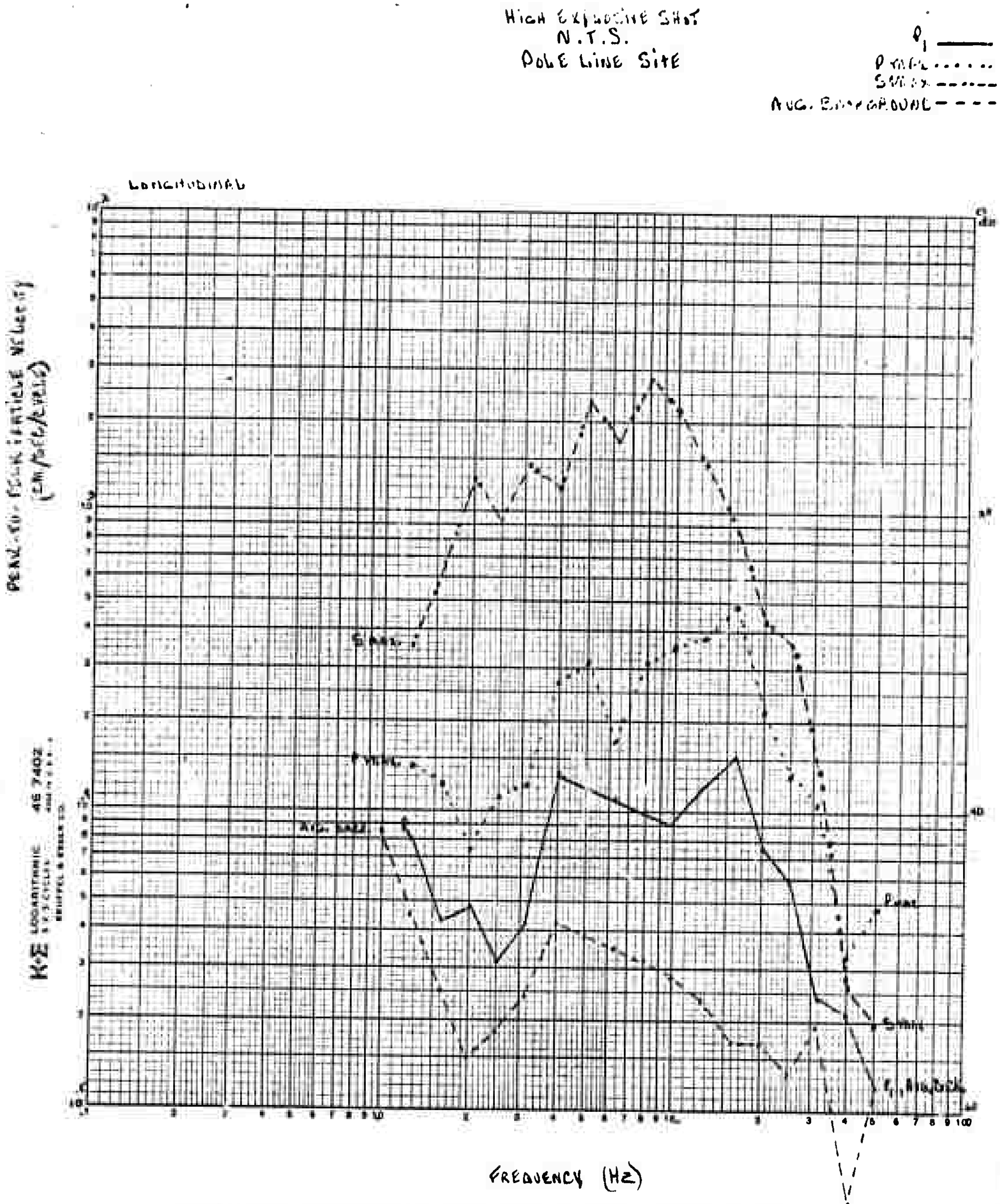


Figure D-4. High Explosive Shot, NTS, East Site (Pole Line Rd.)
(Longitudinal)

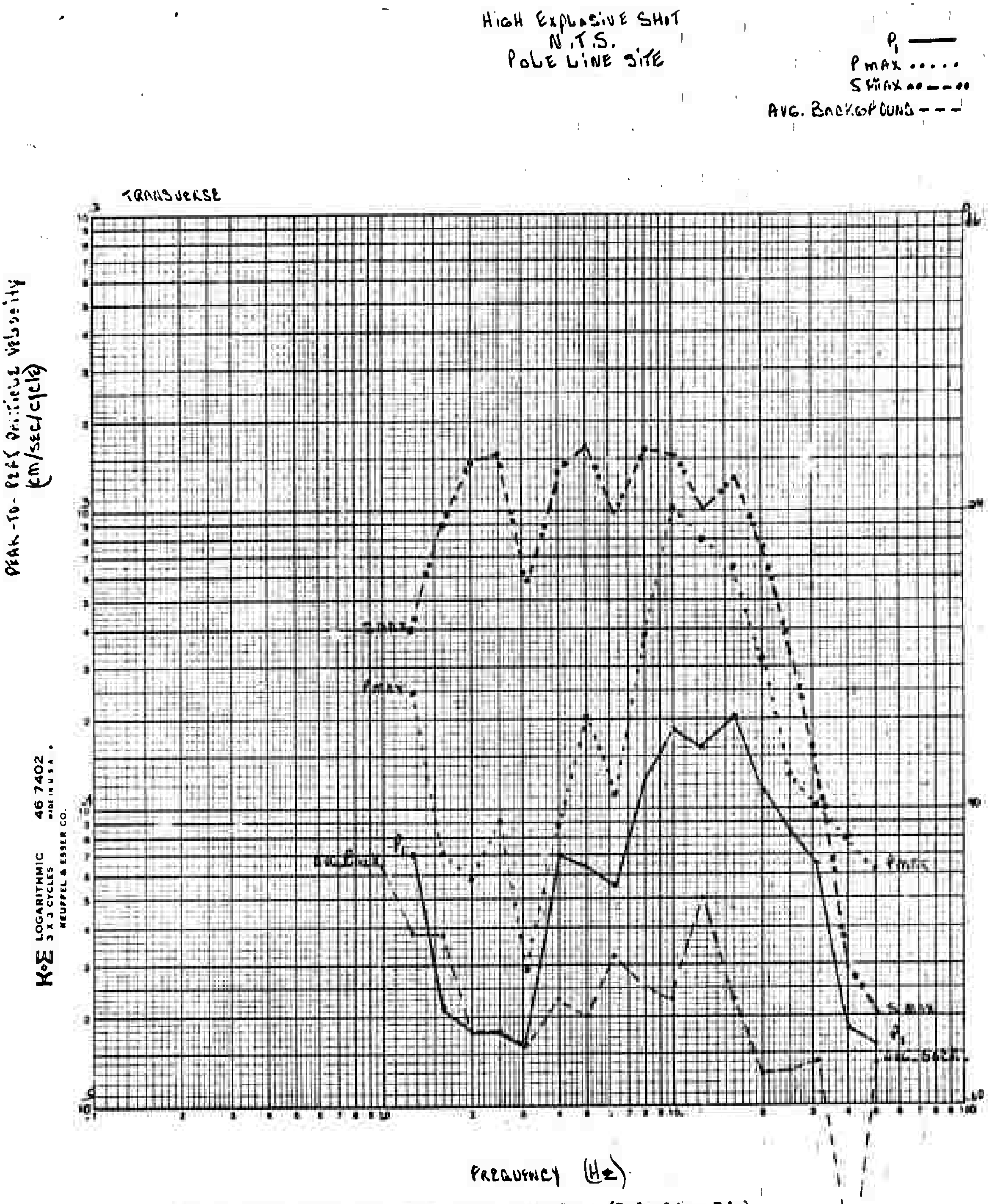


Figure D-5. High Explosive Shot, East Site (Pole Line Rd.)
(Transverse)

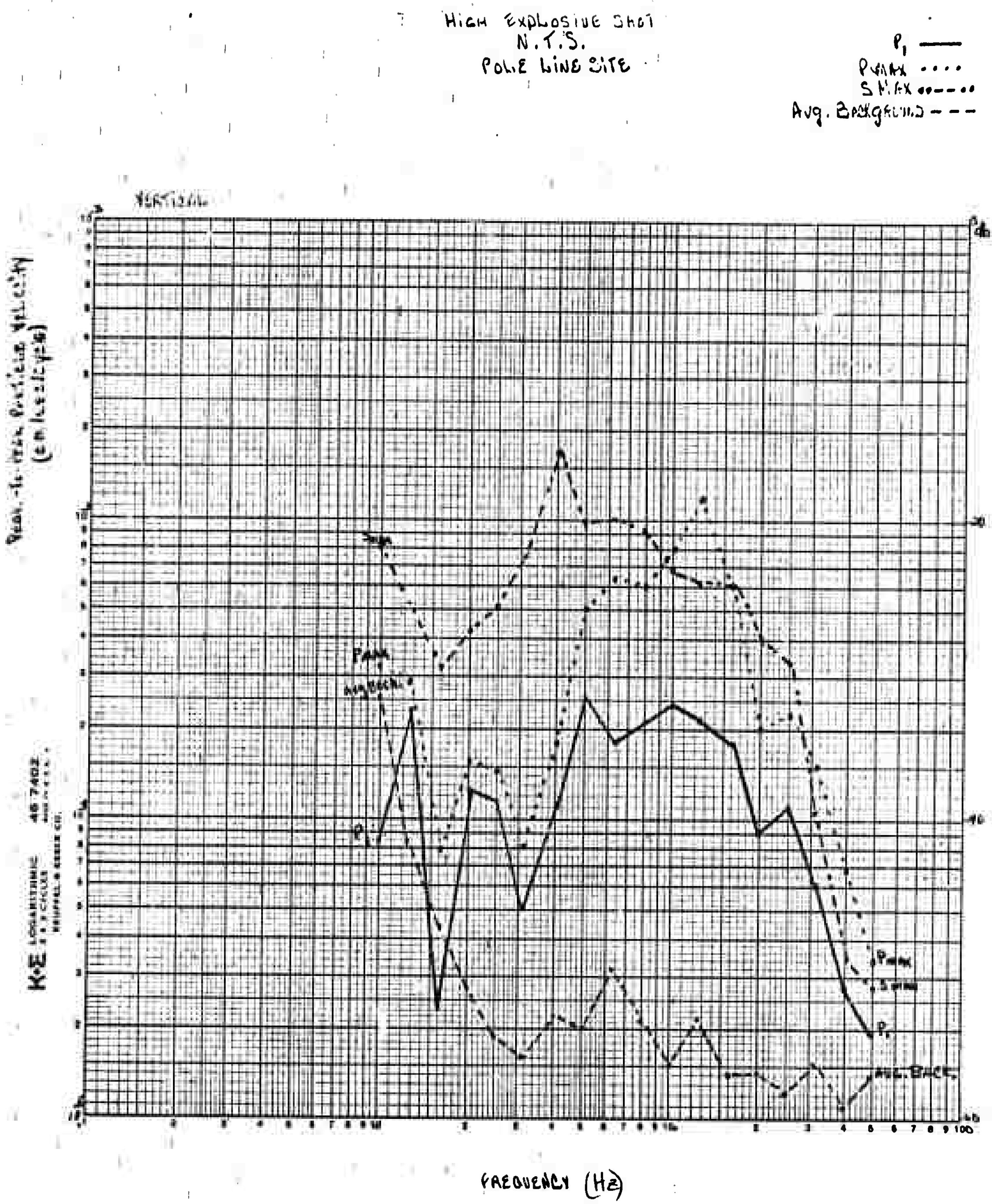


Figure D-6. High Explosive Shot, NTS, East Site (Pole Line Rd.) (Vertical)

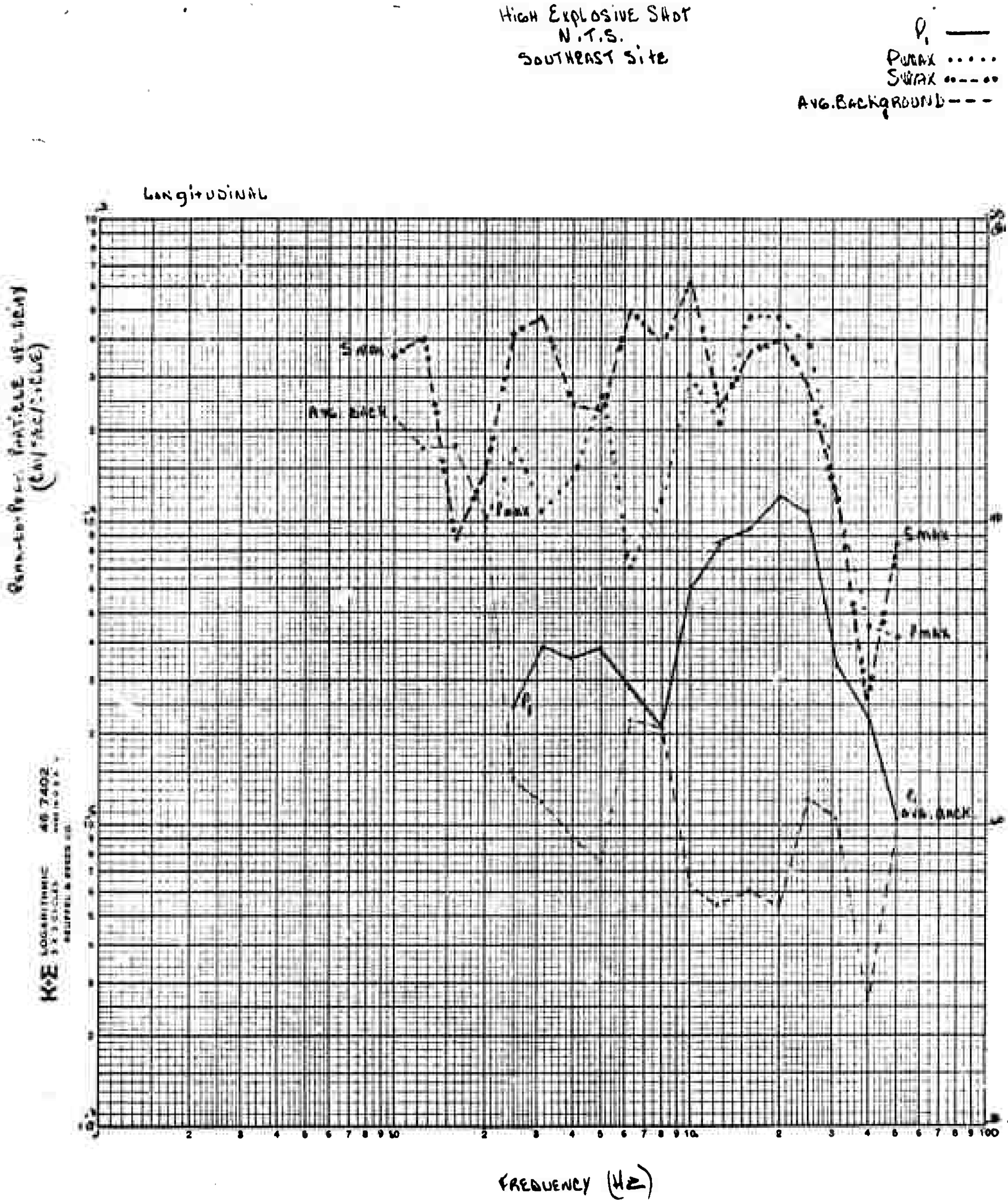


Figure D-7. High Explosive Shot, NTS, Southeast Site, Longitudinal

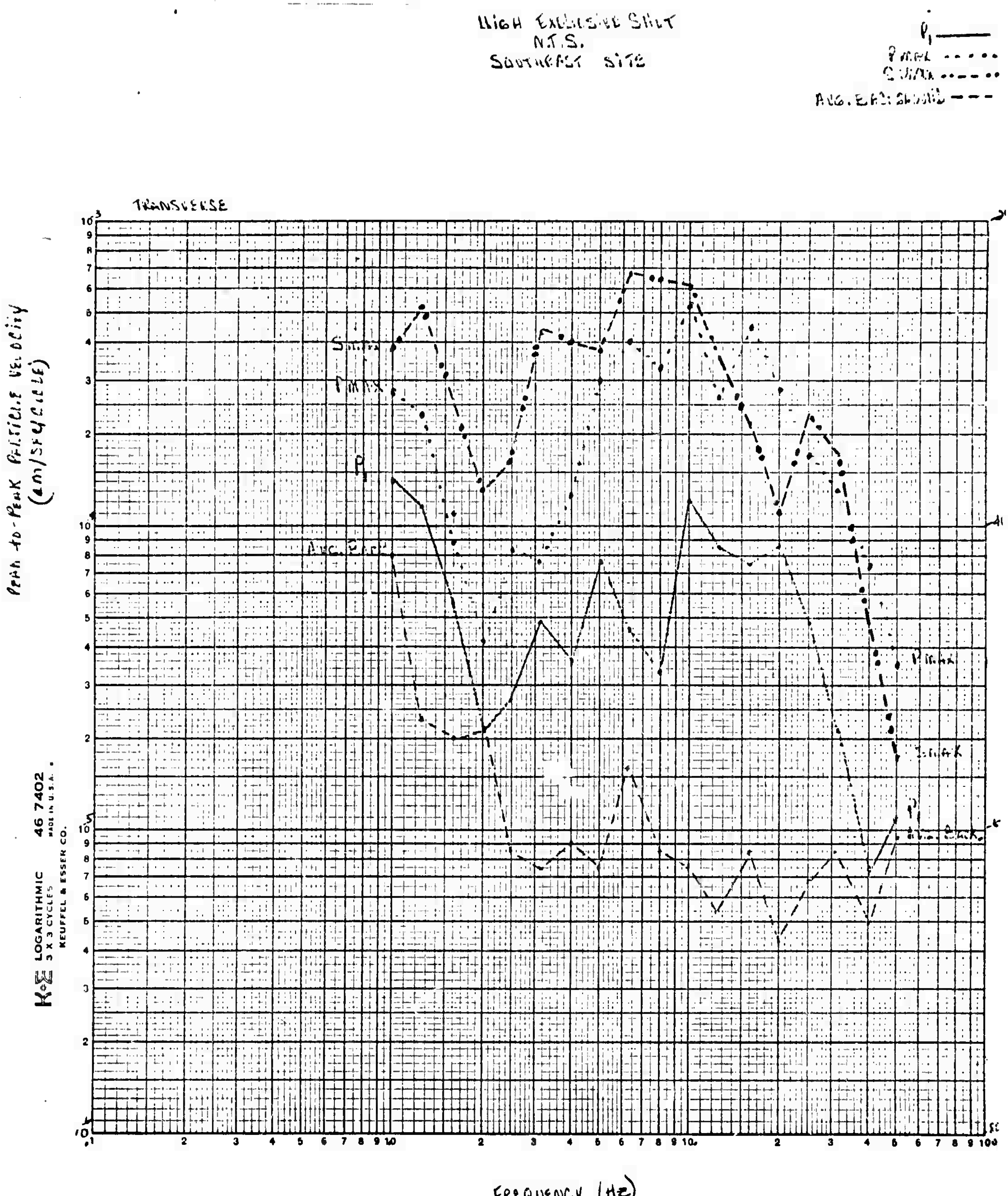


Figure D-8. High Explosive Shot, NTS, Southeast Site, Transverse

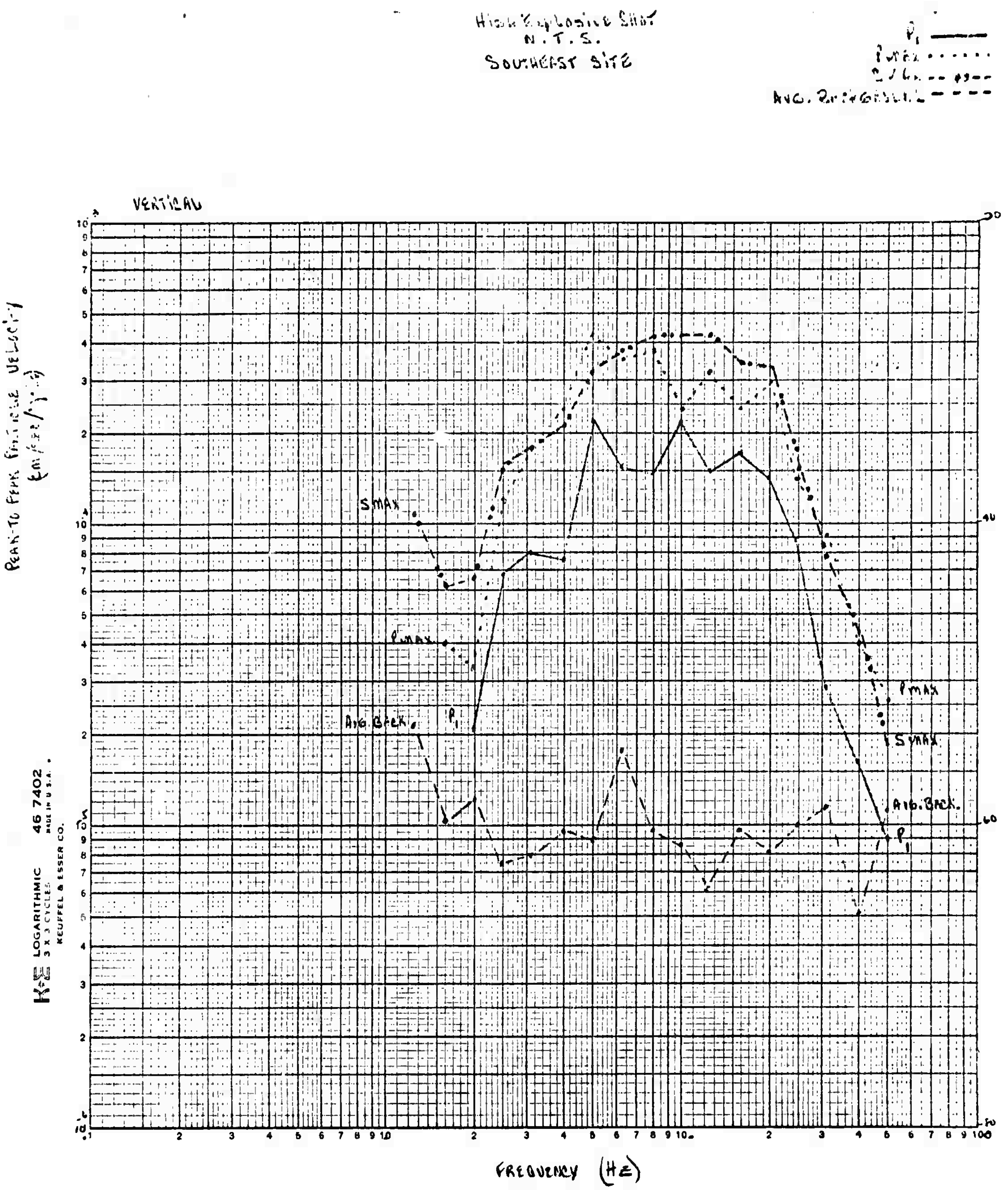


Figure D-9. High Explosive Shot, NTS, Southeast Site, Vertical

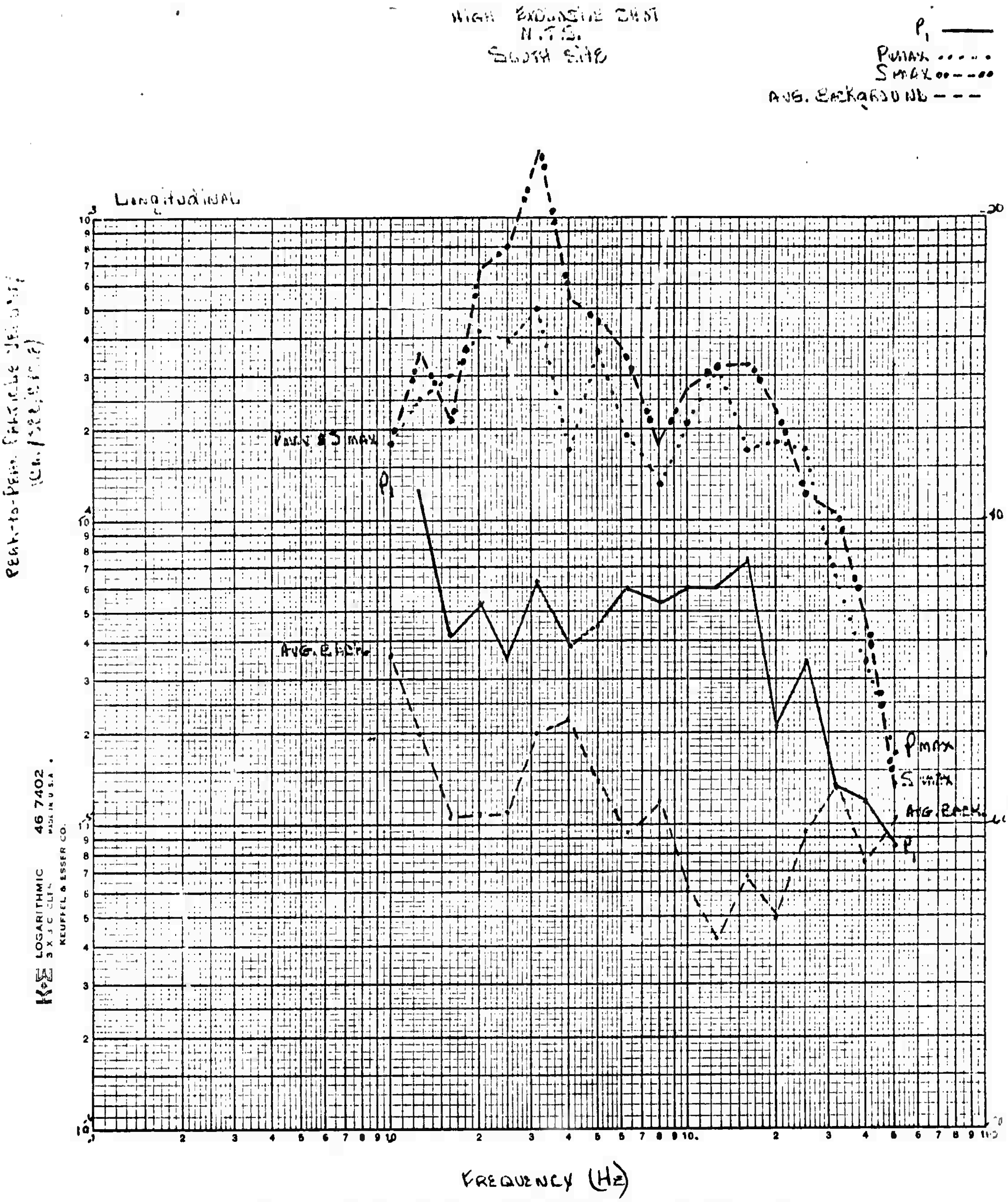


Figure D-10. High Explosive Shot, NTS, South Site, Longitudinal

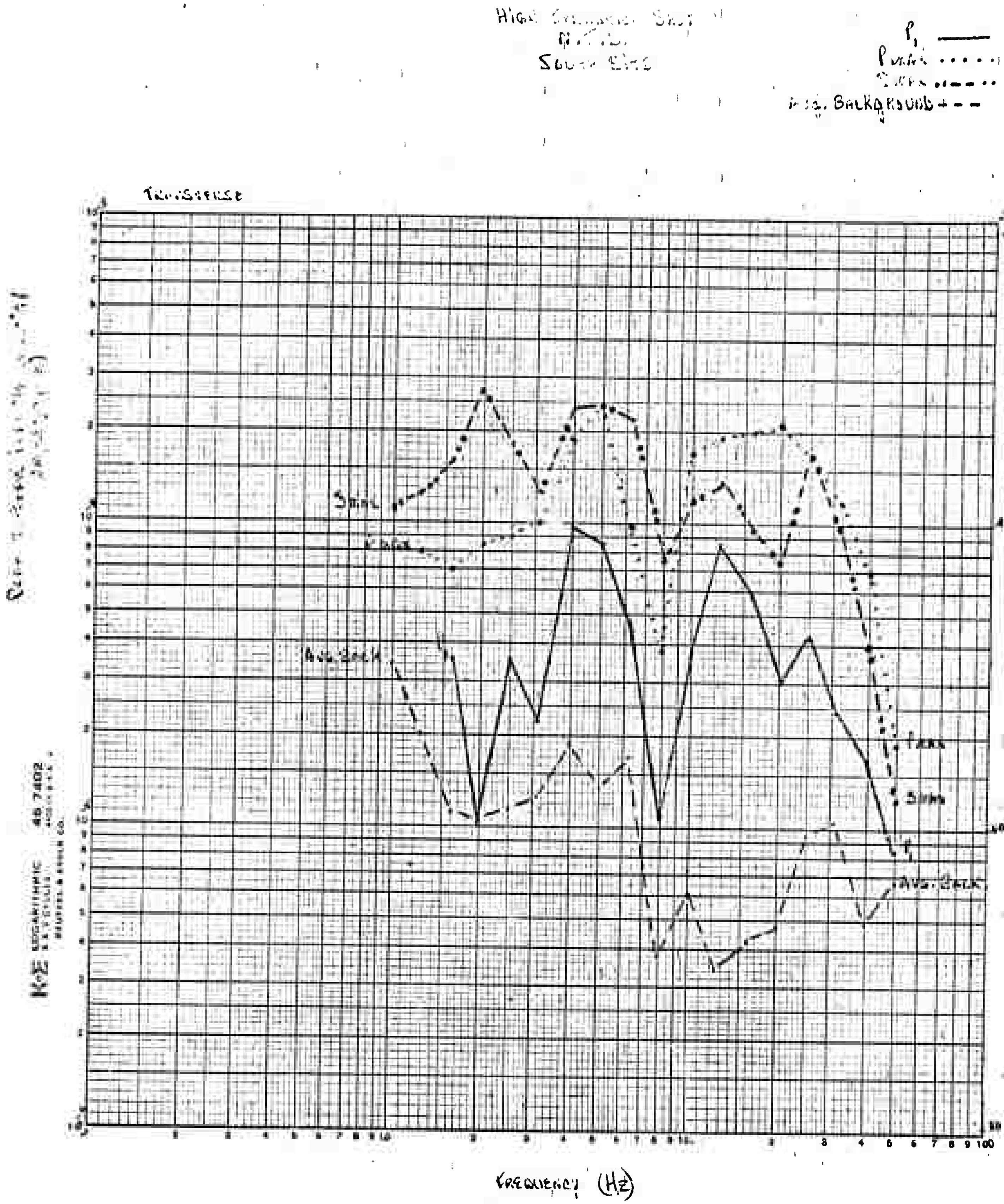


Figure D-11. High Explosive Shot, NTS, South Site, Transverse

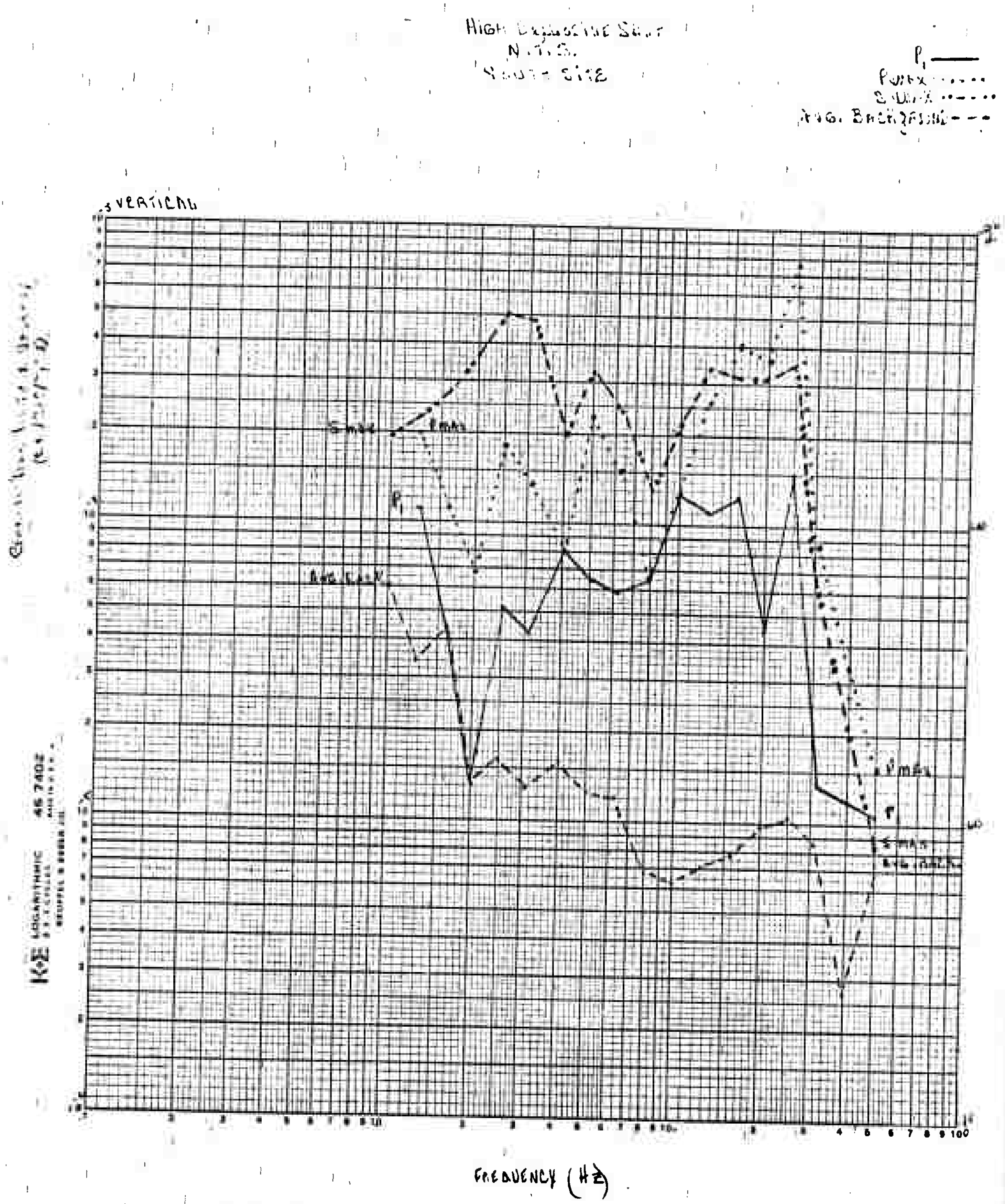


Figure D-12. High Explosive Shot, NTS, South Site, Vertical

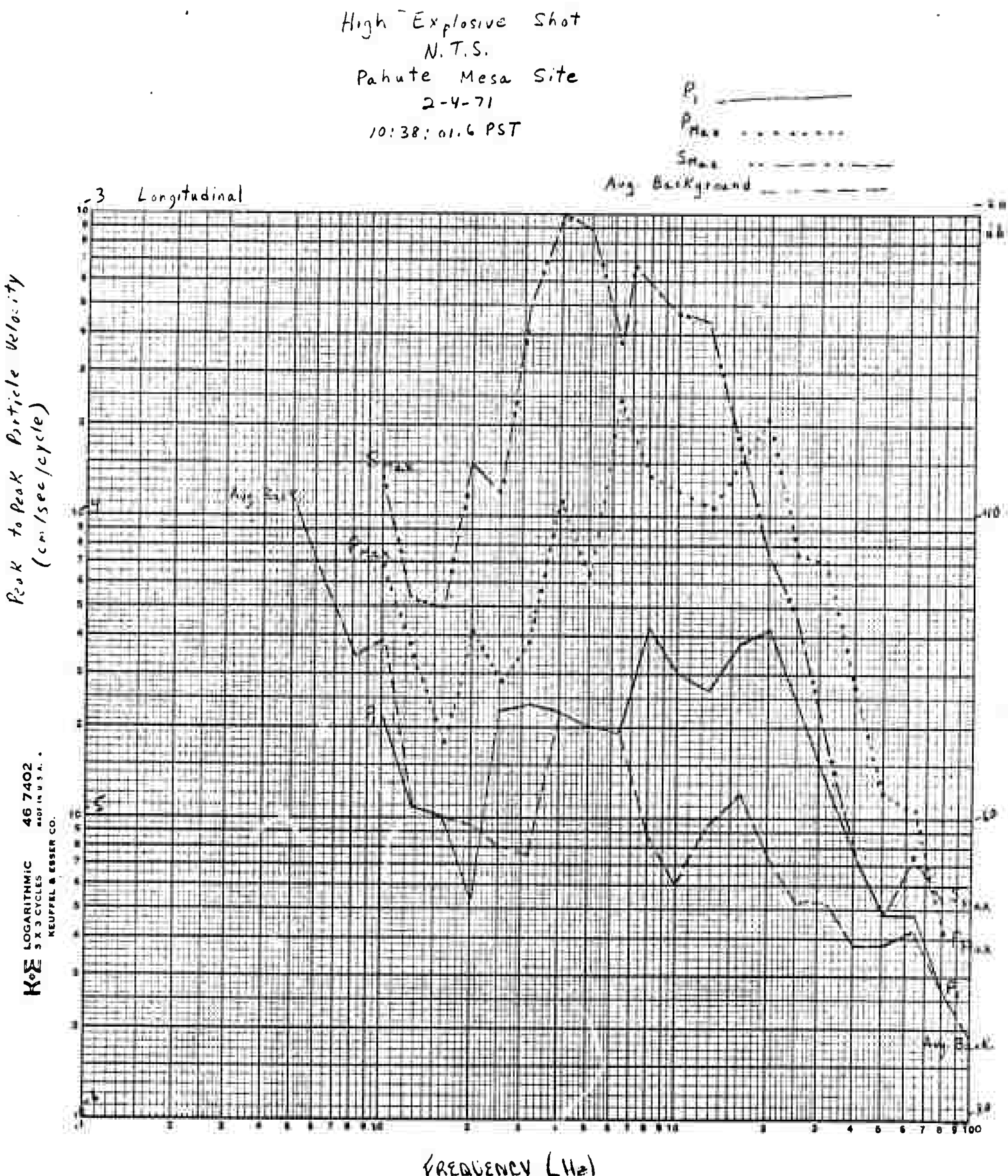


Figure D-13. High Explosive Shot, NTS, Pahute Mesa Site, Longitudinal

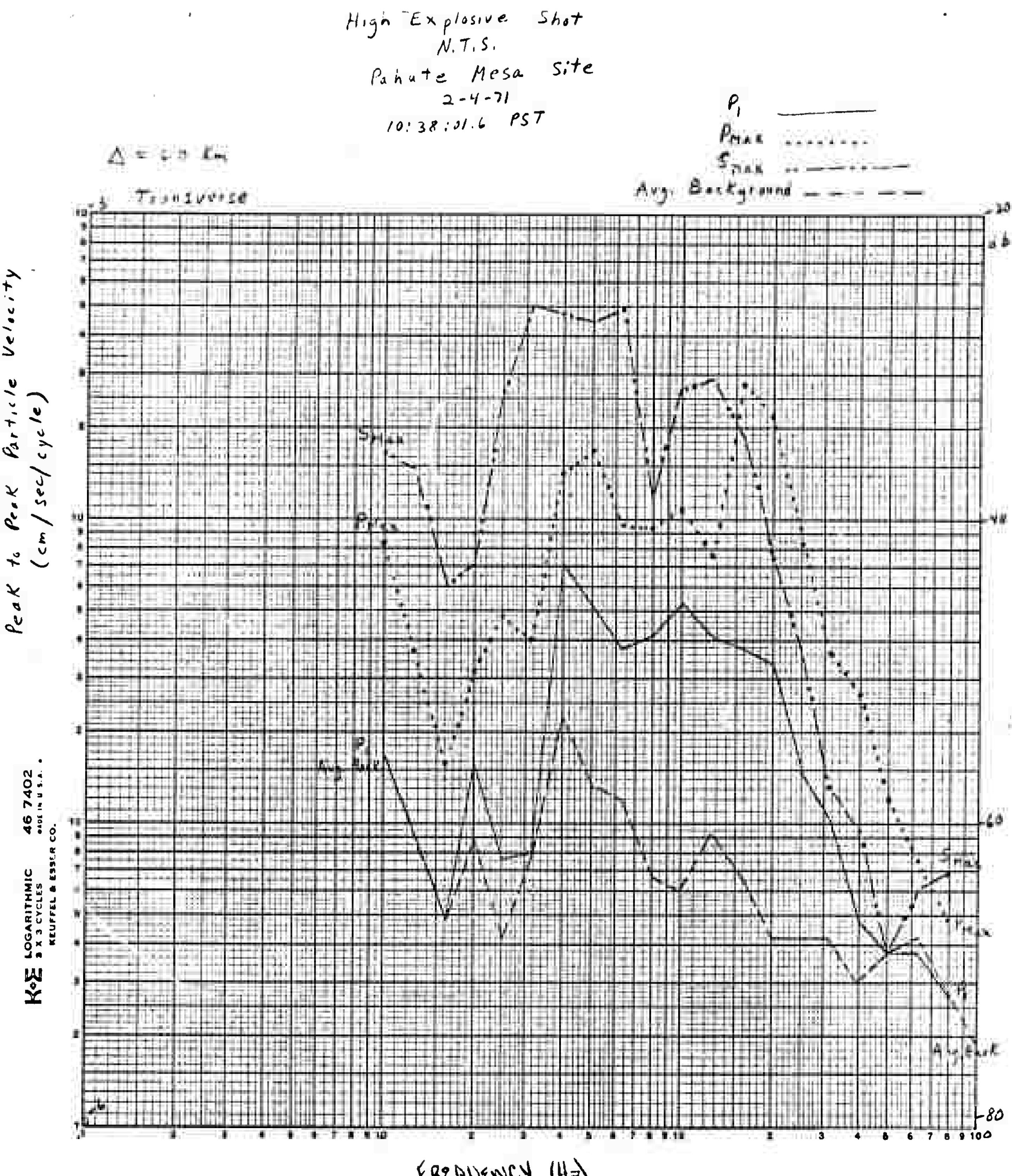


Figure D-14. High Explosive Shot, NTS, Pahute Mesa Site, Transverse

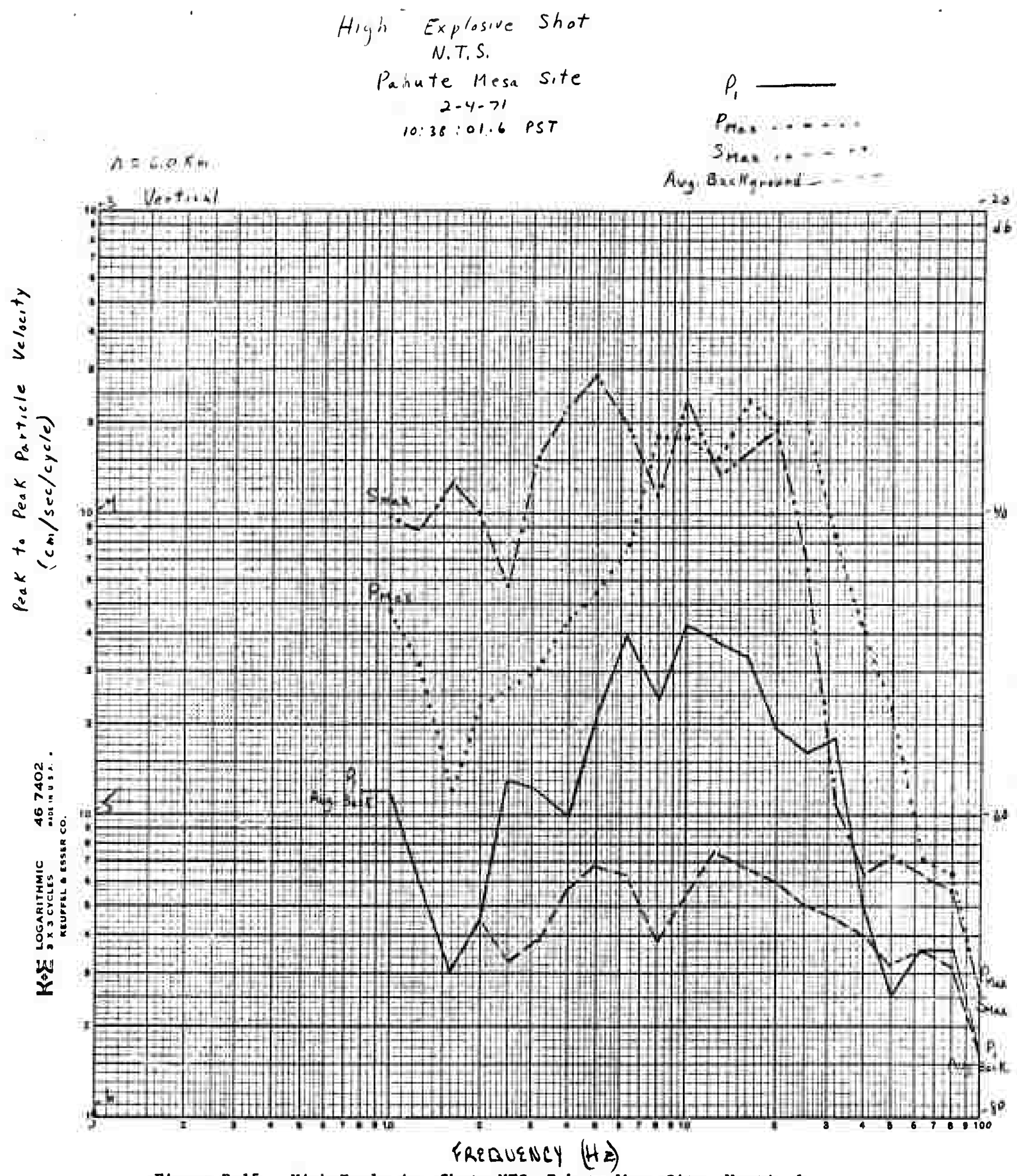


Figure D-15. High Explosive Shot, NTS, Pahute Mesa Site, Vertical